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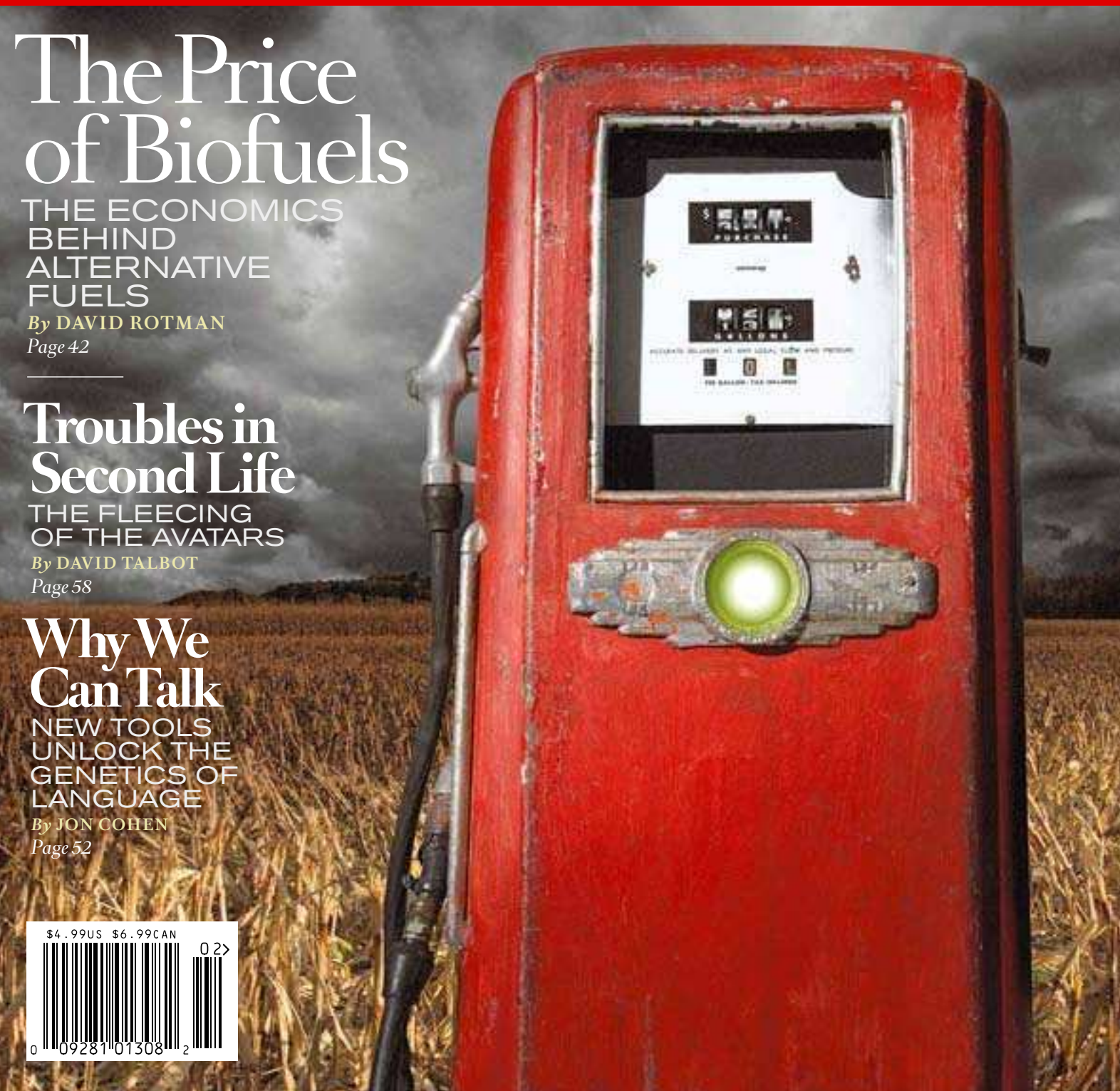

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The world is growing by more than 70 million people a year.

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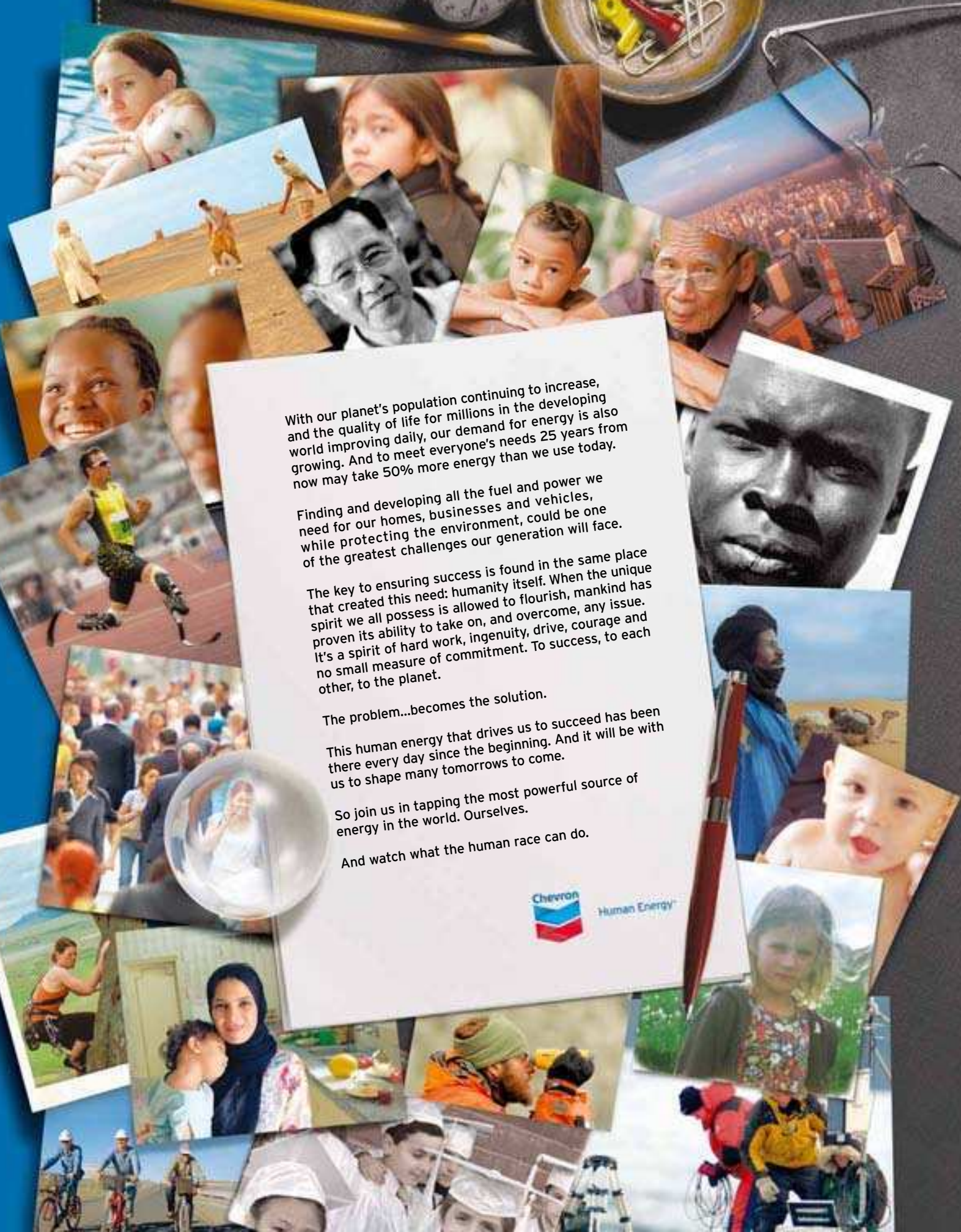

With our planet's population continuing to increase, and the quality of life for millions in the developing world improving daily, our demand for energy is also growing. And to meet everyone's needs 25 years from now may take 50% more energy than we use today.

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COVER
Photo illustration by James Porto; cornfield photo by Marc Bryan-Brown

COURTESY OF BUG LABS (HACK); JUSTIN WARE (BIOFUELS); ADAM FEINBERG (DEMO)

/BIOFUELS

This issue's cover story, "The Price of Biofuels," explores the economic and environmental impact of corn-derived ethanol and other biofuels. Visit our website to watch videos on the debate surrounding the rapidly increasing use of corn ethanol. Among other complaints, critics claim that the diversion of corn to fuel is driving up food prices. In a video recently shot at the St. Paul campus of the University of Minnesota, C. Ford Runge, a professor of economics and director of the university's Center for International Food and Agricultural Policy, explains just how corn ethanol is threatening to "starve the poor." Don't agree? Watch Vinod Khosla, one of the world's most successful venture capitalists, explain why he supports biofuels.

/ARCHITECTURE

This issue's Photo Essay takes you from Prague to midtown Manhattan and points in between, spotlighting creative new buildings by some of the world's greatest architects. All the designs on display were abetted by—and some would have been impossible without—new computational engineering and construction practices. Go to our website for more pictures.

/HACK

The open-source movement is no longer just for software. In a video interview on our website, Peter Semmelhack, CEO and founder of Bug Labs, explains how open-source hardware works.

/DEMO

Want to watch pieces of plastic powered by heart cells swim through a solution, or bend and contract when zapped by a pacemaker? In Demo we explain how researchers at Harvard University are using living heart tissue harvested from rats to form tiny actuators. The work could have applications in drug testing and robotics. See these amazing machines in action on our website.

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De Technologia non multum scimus. Scimus autem, quid nobis placeat.

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New England and Midwest
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barry.echavarria@technologyreview.com
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Mid-Atlantic and Southeast
Clive Bullard
cbullards@cs.com
845-231-0846

Northwest and Southwest
Patrick Viera
patrick.viera@technologyreview.com
415-659-2982

Northwest
Steve Thompson
stevet@mediacentricinc.com
415-435-4678

France
Philippe Marquezy
philippe.marquezy@espacequadri.com
33-1-4270-0008

Germany
Michael Hanke
michaelhanke@heise.de
49-511-5352-167

Europe
Anthony Fitzgerald
mail@afitzgerald.co.uk
44-1488-680623

China, Hong Kong, Philippines, and Thailand
Herb Moskowitz
mediarep@netnavigator.com
852-28-38-87-02

Japan
Shigeru Kobayashi
shig-koby@media-jac.co.jp
813-3261-4591

South Korea
S. Y. Jo
biscom@unitel.co.kr
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JOHN HOCKENBERRY, a distinguished fellow at the MIT Media Lab, spent nine years as a correspondent for *Dateline NBC* before leaving the network in 2005. In this issue's essay, "You Don't Understand Our Audience" *(p. 64)*, he recounts the differences he had with NBC over basic issues of journalism—but also over related questions about how television news ought to use technology. "The more I thought about my experiences," says Hockenberry, "the more technology seemed to be an important theme of numerous frustrating trends in media. The tech issues in media are not well understood but are much talked about; the transformations in information delivery and discourse are hard to identify. So many of the conventions of media, storytelling, and news are up for grabs right now."

Hockenberry will be the cohost of a multiplatform morning news show set to launch later this year on public radio.

JON COHEN, in "The Genetics of Language" *(p. 52)*, visits with Daniel Geschwind, a neurogeneticist at the University of California, Los Angeles, who is working at the intersection of behavioral genetics and evolutionary biology. Researchers like him want to know how humans evolved the ability to speak. "Philosophers, psychologists, linguists, and animal behaviorists have had huge debates about whether our speech and language skills truly separate us from other animals," says Cohen. "Now geneticists have entered the fray, and they can point to clear-cut differences in human genes associated with speech and language. So now the nebulous—often incomprehensible—arguments about the syntax and grammar skills of different species

have given way to precise distinctions in DNA that make humans the odd ones out."

Cohen is a correspondent for *Science* and the author of *Shots in the Dark: The Wayward Search for an AIDS Vaccine* and *Coming to Term: Uncovering the Truth about Miscarriage*. He is currently writing a book about how new research redraws the lines that separate humans from chimpanzees.

MICHAEL CHOROST has his cochlear implant to thank for his ability to hear—and yet he wishes it were *fully* implanted (he has to wear a processor on his ear). That's why he was interested in the Carina, a fully implantable hearing aid made by Boulder-based Otologics, which is now in clinical trials *("The Naked Ear," p. 72)*; its technology might one day be useful for cochlear implants. "These guys are engineering on the edge," he says. "The engineer who showed me their manufacturing plant told me proudly that the lithium-ion batteries they use are the same ones that went on the Mars rovers. That makes sense: in both cases, the environment is tough and the stakes are high."

Chorost is the author of *Rebuilt: How Becoming Part Computer Made Me More Human*.

JOHN POLLOCK has long followed the work of Norman Borlaug, who won the Nobel Peace Prize in 1970 for producing high-yield wheat varieties that resist disease and can be grown in disparate climates. When, during the writing of his review *("Green Revolutionary," p. 74)*, Pollock found a rare quiet week in the agronomist's schedule, it clashed with his 40th birthday. But the decision to fly from England to Mexico "took 50 milliseconds," he says. "There are very few humans of his stature

on the planet at any one time. And what better way to spend your 40th than breaking bread with a Nobel laureate in his 10th decade?"

Pollock has consulted to organizations and governments, often on international development and Africa. He now works for Turquoise Frog, a private think tank.

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QUANTS AND WALL STREET

Leave it to a technology magazine to publish the best financial-reporting story of the year. Bryant Urstadt's report ("The Blow-Up," November/December 2007) is the first and only truly penetrating piece of reporting and analysis on the role that quantitative hedge funds played in a tempest-tossed summer on Wall Street. Kudos.

Nick Schulz
Washington, DC

Isn't it ironic? Statistical quant models made billions of dollars for hedge funds from random stock-market movements. But when success expanded those hedge funds to make up a large part of that market, those quant models ended up modeling their own results, which were anything but random. The feedback loop from models trying to model themselves had all the hallmarks of a bad episode of *Star Trek*. It's just too bad investors had to lose $2.1 trillion in market valuation in order to see it come to life.

Carl D. Howe
Maynard, MA

Your piece states that quants want a unified theory of finance. But even if they have one, it will not help them, any more than a unified theory in physics will improve long-range weather forecasting. Major gains in weather forecasting have come from denser sensor networks and, especially, vastly increased number-crunching capability. Still, the short-term forecasts in my city were significantly wrong last week.

And unlike meteorologists, the quants are within the system they are studying. They *are* the system, and when they employ new knowledge, they change the system and render their models incorrect.

Allen Burke
Orlando, FL

Werner Heisenberg described the limits on the simultaneous knowability of a particle's speed and position. Most technologists view this principle as revealed cosmic truth, with many analogues in what passes for our real world. The stock market is one such analogue. If stocks' values could be predicted with certainty, then they would be. And stocks would take on all the entertaining dynamics of life insurance.

Probably sooner than later, a Heisenberg will emerge to judge the quants. And the result will be highly quantified. Meanwhile, and probably afterward, informed intuition will continue to dominate long-term (responsible) trading.

Walker Sloan
Berlin, MA

As a longtime participant in capital markets, I feel certain that the quants aren't to blame for the August collapse; we are. For a variety of reasons, global availability of short-term debt instruments is at a low while demand is at an all-time high. Further, global interest rates look unattractive.

The problem is that there is no such thing as a free lunch, or free yield. Although the quants made the market possible and helped keep it working, it was global demand for a slightly shinier piggy bank in which to keep their cash that created the August collapse and its ongoing financial fallout.

Duncan Stewart
Toronto, Ontario

ON J. ROBERT OPPENHEIMER

In your most recent editor's letter ("Oppenheimer's Ghost," November/December 2007), you state, incorrectly, that Oppenheimer "was chairman of the U.S. Atomic Energy Commission." He was never AEC chair. He was chair of the General Advisory Committee (GAC) to the AEC from 1946 to 1952. Cutting his ties to the AEC and revoking his top-secret clearance was the objective of the infamous inquisition-style Oppenheimer trial in 1954.

William E. Murray
Palo Alto, CA

EXPECTATIONS ABOUT PRIVACY

Mark Williams, in his review of Daniel Solove's *The Future of Reputation* ("The Talk of the Town: You," November/December 2007), writes that "in villages, everybody knew everybody else's business; personal privacy and anonymity are social constructs that achieved their current legitimacy when increasing numbers of people started moving to cities in the 18th and 19th centuries." That claim is inconsistent with the experience of anyone who has grown up in a rural setting. Farmers and their neighbors have traditionally spent long hours alone in the fields or traipsing through silent, desolate, and dangerous landscapes. (A good thing, too, since distance, not easy proximity, is the furnace of creativity and innovation.)

We should all value privacy. Once it's gone, there's little chance of its being recovered.

David Dumitru
St. Louis, MO

MARS

You have had quite an impact on the Mars science community with your wonderful graphic story ("Mission to Mars," November/December 2007). The story is circulating among all the teams that you wrote about, and of course, each believes that the story is about them. My children have (finally) decided that I must be famous, now that I'm in a comic. The well-written, exciting, and accurate story—together with the terrific art—brings back to all of us the days of struggle and reminds us, once again, to wish Peter Smith and the *Phoenix* team the best of luck.

Daniel J. McCleese
Chief scientist, Jet Propulsion Laboratory
Pasadena, CA

HOW TO CONTACT US
E-mail letters@technologyreview.com
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The Geography of Innovation

THE GLOBAL CULTURE OF VALUABLE, FRESH THINKING.

What is innovation, and how may it best be fostered by companies and other organizations?

I am just back from three weeks of travel, having visited biotechnology startups in Germany and media companies in India, and I return convinced that what is called the "innovation economy" is its own nation, whose citizens share a common way of seeing and working. (Earlier speculations on the subject were published on this page in the September/October 2006 issue.)

It is best to begin by asserting what innovation is *not*. Innovation is not invention, and still less is it scientific discovery. An innovation must be valuable, which means it must exist in a market or some more general social context of supply and demand.

A special report published by the *Economist* last October and edited by Vijay Vaitheeswaran floated a definition proposed by the Organization for Economic Coöperation and Development, a think tank. Innovation, according to this formulation, encompasses "new products, business processes, and organic changes that create wealth or social welfare." The *Economist* also cites a simpler definition from Richard Lyons, the chief learning officer of Goldman Sachs: "fresh thinking that creates value."

Either definition will do, although both smack of the jargon of management consultants. For me, neither definition captures the discomforting novelty of true innovations. Innovation disrupts our existing way of doing business or creates entirely new ways of doing things. Always, innovations are embraced by those who find them valuable, are hyperbolized by the companies and organizations that benefit from their adoption, but are resisted by incumbent companies and organizations and conservative customers and users. When an innovation is sufficiently accepted by enough people, however, resistance to that innovation becomes feckless and fruitless—it amounts to an attempt to pretend that reality is other than how it is.

Expressed this way, it might seem that innovation, while possessing the force of the inevitable, would be regarded warily by institutions whose function is to promote continuity and stability. Indeed, some bureaucrats and religious leaders would prefer to mitigate innovation's influence.

But in the United States and Europe, and even more so among those who, no matter their physical location, really inhabit some outpost of the innovation economy, there is a common conviction that innovation is a powerful force for good that should be encouraged and lauded. That's because innovation expands human possibilities and is the single most important cause of economic growth. In the same special report, the *Economist* cited the McKinsey Global Institute's demonstration that competition and innovation, and not information technology alone, led to the productivity gains around the world during the 1990s.

This being so, can governments do anything to increase innovation among companies and organizations within their borders? Not much. Ever since I became the editor of *Red Herring* magazine in the mid-1990s, I have heard countless story pitches about the establishment in different countries of government-supported technology clusters or hubs. All were to have competed with Silicon Valley and Cambridge, MA. All ignominiously failed, with the possible exception of the technology cluster in Cambridge, England. The things that governments can do to foster innovation are limited and simple: fund research based on long-term discovery, devise regulations and tax incentives that promote risk capital and entrepreneurialism, protect intellectual property, uphold the rule of law, and maintain flexible labor markets. Otherwise, governments do best by doing least.

Rather, innovation seems to be more the product of culture and methodology. The culture of innovation tolerates failure and smiles upon creativity. But such a culture is not enough in itself: successful innovation also pitilessly rejects bad ideas when their promise has been exhausted and efficiently executes the development and commercialization of the best ideas.

Wherever I go, innovators seem to instinctually recognize these paired demands of culture and methodology—and, more important, they burn with a passion for innovation itself.

Attentive readers will have noticed that *Technology Review* looks a little different. Don't repine: we've changed very little. Beginning on page 27, you'll find a new section, To Market, that will follow the emerging technologies we write about elsewhere as they become commercial products. Also, we've shifted around our furniture. Regularly recurring pages that enjoyed some propinquity of subject or style are now contiguous: we've placed Notebooks, our guest columns, directly after this page and Hack, our deconstruction of a particular technology, in the back of the magazine, where it now abuts Reviews. Otherwise, the changes are superficial, although we hope you find them pleasing and useful: we have new fonts that are more legible, a new palette that is brighter, a new treatment for our charts that is more straightforward, and new section headers that more obviously announce the different parts of the magazine. We think the new design is very elegant; but write and tell me what *you* think at jason.pontin@technologyreview.com. —*Jason Pontin*

MARK OSTOW

Technology Review
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I am the future of technology.

TECHNOLOGY REVIEW READER:

GUILLAUME COHEN
FOUNDER & CEO,
VEODIA

As CEO of Veodia, an innovative broadcasting company that's pushing the boundaries of online video, Guillaume must keep abreast of the latest technology. He relies on *Technology Review* because "it's for leaders who seek a more fundamental inner understanding of the world to set tomorrow's trends and disrupt industries through real innovations. It has this unique balance of fundamental science and the analysis of its impact on our lives in the future." Guillaume and his team at Veodia are harnessing emerging technology to create strategic advantage. In doing so, Veodia is on its way to becoming an industry leader and *Technology Review* has helped Guillaume "stay on top of my field and challenge it too."

Thomas J. Gustainis

www.technologyreview.com/reader

NOTEBOOKS

ENERGY

Cellulosic Biofuels

GREGORY STEPHANOPOULOS EXPLAINS CHALLENGES IN CONVERTING BIOMASS TO BIOFUELS.

IT IS NOW well accepted that for several reasons, corn ethanol will have a rather limited role as a renewable substitute for petroleum-derived liquid transportation fuels. The shortcomings of corn ethanol have sparked interest in the production of other types of fuels—such as higher alcohols, oils, and hydrocarbons—from renewable biomass feedstocks *(see "The Price of Biofuels," p. 42)*. While the potential economic, environmental, and security benefits of such cellulosic biofuels are clear, many hurdles need to be cleared before they can begin to make a difference in the overall supply of liquid fuels for transportation.

There are three major challenges in the economical conversion of biomass to biofuels. The first is to optimize the yield and quality of the biomass, as well as to work out the logistics of securing, transporting, and processing the large volumes that will be required to support the operation of future biorefineries. New ways of harvesting, preprocessing, and transporting biomass will be necessary before it's cost-effective for biorefineries to import biomass from more than 15 or 20 miles away. One scheme is to establish satellite collection and pretreatment facilities from which slurry biomass is transported by pipelines to the main biorefinery. One can envision pipelines where cellulose hydrolysis, the slow process by which cellulose is broken down into usable sugars, takes place while a slurry is transported from the satellites to the main biorefinery.

The second challenge is to improve the way biomass is broken down, so as to yield a stream of abundant, inexpensive sugars for fermentation. This may be accomplished by modulating the plant's content or by genetically engineering self-destruction mechanisms into it, to be initiated after harvest and at the right processing time. Another solution might be to pursue more-active and less expensive conventional cellulolytic enzymes and perhaps new physicochemical methods, such as solubilization of cellulose by ionic liquids.

The last step is to construct new pathways that convert sugars into the various target biofuels in organisms such as yeast and *E. coli*. Here lies the third challenge: to engineer *optimal* pathways. There is an important difference between stitching reactions together by importing genes from other species and constructing an optimal pathway that converts all sugars at maximum yields and efficiencies, producing biofuels at high concentrations. Making biofuels cost-competitive will require the latter, but to achieve that goal we must engineer strains of yeast, *E. coli*, or other organisms with high tolerance for the toxicity of both the initial biomass hydrolysate and the final biofuel product.

No single breakthrough is likely to bring us to the point of efficient biofuel production—superbugs, consolidated bioprocessing, or blooming deserts notwithstanding. Rather, it will probably take many advances on several scientific and technological fronts, underlining the importance of a systems approach. A number of promising technologies, both biological and chemical, are in development. Economics will determine the winners, no matter what kinds of plants get built in the short term. It is also important to bear in mind that specific techniques may interfere with each other to obstruct a modular approach—by, say, undermining a well-engineered strain's ability to work with a different feedstock hydrolysate. So far, solutions to this complex, multidimensional problem have been sought within the confines of biology or chemistry, but the real answer may very well lie in a hybrid process that combines the best each field can offer. TR

GREGORY STEPHANOPOULOS IS W. H. DOW PROFESSOR OF CHEMICAL ENGINEERING AND BIOTECHNOLOGY AT MIT.

INTERNET

Second Chance for Second Life

VIRTUAL WORLDS NEED THE FREEDOM TO SELF-CORRECT, ARGUES ROBERT BLOOMFIELD.

DURING A SUMMER of (virtual) scandals, lawyers and the press routinely referred to the financial markets of the immersive digital playground Second Life as "lawless" and "a Wild West" *(see "The Fleecing of the Avatars," p. 58)*. The flip side of these derogatory terms is that Second Life is a libertarian's dream. As one who studies financial markets, I hope regulators will give markets such as Second Life's enough freedom for us to learn something about how to regulate real-world markets, and when not to try.

In medicine, we assess the effectiveness of a drug partly by denying it to a control group. But the high stakes of experimenting with deregulation of large real-world markets make it hard to get much empirical evidence about what kind and degree of regulation make the most sense, or what practices, in the

MARC ROSENTHAL

absence of regulation, are most successful in protecting investors and fostering liquid markets. That's one reason Second Life excites economists: at little cost, they can create a regulation-free control group.

Linden Lab, which owns Second Life, maintains a largely hands-off policy regarding disputes between residents. If you start a business selling virtual televisions that don't work, Linden Lab is unlikely to step in when people complain. It's also unlikely to take action if you list a new company on a Second Life stock exchange, then take investors' money and spend it on virtual clothing or real-world pizza. Instead, residents are forced to take matters into their own hands. One started the Virtual World Business Bureau, a virtual version of the Better Business Bureau that seeks to resolve business disputes and provide information that will help people avoid untrustworthy parties. Residents running and listing on stock exchanges created the Second Life Exchange Commission to set minimum standards for identity and financial disclosure.

How will this experiment in unregulated commerce turn out? If these two bureaus cannot earn the respect of the Second Life community, I see two possibilities. One is that as commercial activity grows in Second Life, scandals will get large enough to attract the attention of real-world regulators. Alternatively, the markets might fail to thrive because they cannot engender enough trust, and residents will gladly invite the regulators in. Of course, if the efforts within Second Life actually turn out to work—reducing incidence of fraud, increasing business transparency, and establishing mechanisms for trusted interactions—regulators will probably be willing to delegate oversight (as they largely do in the case of real-world accounting standards, for example). And it might just show that actual economies can operate with less or lighter regulation. Any of these three outcomes will teach us some valuable lessons. I hope regulators will have the patience to learn from Second Life's small mistakes. TR

ROBERT BLOOMFIELD IS A PROFESSOR OF MANAGEMENT AND ACCOUNTING AT CORNELL UNIVERSITY'S JOHNSON GRADUATE SCHOOL OF MANAGEMENT.

ARCHITECTURE

Build from Scratch

WILLIAM J. MITCHELL SAYS THAT TECHNOLOGY MAKES ARCHITECTURAL INNOVATION POSSIBLE.

FROM TIME TO TIME, harrumphing old-timers, tabloid columnists, and talk radio hosts get in a twist about buildings that twist instead of going straight up and down. They rail against structures that defy conceptions of rationality they take to be self-evident *(see "The Building, Digitally Remastered," p. 34)*.

But these conceptions are framed by unexamined assumptions about technological possibilities and social priorities. They are framed by ideology.

If, for example, your primary goal is to minimize the construction cost of a large project, it is rational to try to minimize the surface-to-volume ratio and thus the amount of enclosing material. This strategy produces fat, dumpy, boxy buildings that leave most of their inhabitants deep in interior spaces far from windows.

But people like natural light, air, and views of the outside. So if you care more about that, it is rational to *maximize* surface-to-volume ratio, producing a highly reticulated building like MIT's Stata Center. This democratic strategy puts many people on the exterior and gives a lot of them corner offices.

If you are an unregenerate Taylorist in your conception of productive work, it is rational to maximize the amount of office or laboratory space on a floor while shrinking circulation and public areas. This is what architects know as maximizing the net-to-gross ratio. It produces grim, cramped interiors like those of the older laboratories at MIT, with long, straight central corridors.

But if you believe that innovation depends upon serendipitous encounters, intellectual cross-connections, and informal social networks within organizations, it is rational to provide plenty of space to support such social dynamics. You will invest more heavily in public spaces—generous interior streets and piazzas—instead of mere circulation channels.

If you think construction should be about achieving economies of scale through standardization and mass production, it is rational to design buildings consisting of repeating floors composed of repeating rooms made from repeating components on repeating grids.

But if you value responsiveness to varied local needs and conditions, celebration of diversity and complexity, and the joy of the unexpected, you might want something more from architecture. And if you understand the possibilities of combining computer-aided design with digitally controlled fabrication and assembly, you will know that complex, nonrepetitive buildings like the "Gherkin" in London or the Turning Torso in Malmö, Sweden, can now be created without excessively high costs.

Technology does not determine architectural form; it serves as an enabler. New tools—most recently digital design and construction technologies—open up new spatial and material possibilities for exploration. Daring and imaginative architects have seized the opportunity. TR

WILLIAM J. MITCHELL IS ALEXANDER DREYFOOS PROFESSOR OF ARCHITECTURE AND MEDIA ARTS AND SCIENCES AT MIT.

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DISPLAYS

E-PAPER, IN LIVING COLOR

Materials advances could bring color, video, and flexibility

GADGETS LIKE the Sony Reader and the newer Amazon Kindle let people read downloaded e-books on crisp displays that are clear even in bright sunlight. But while the devices reproduce the experience of reading ink on paper, they're rigid, monochrome, and relatively slow to switch pages. Laboratory advances from E Ink of Cambridge, MA, whose technology is used in both e-readers, are pushing electronic-paper technology into color and video.

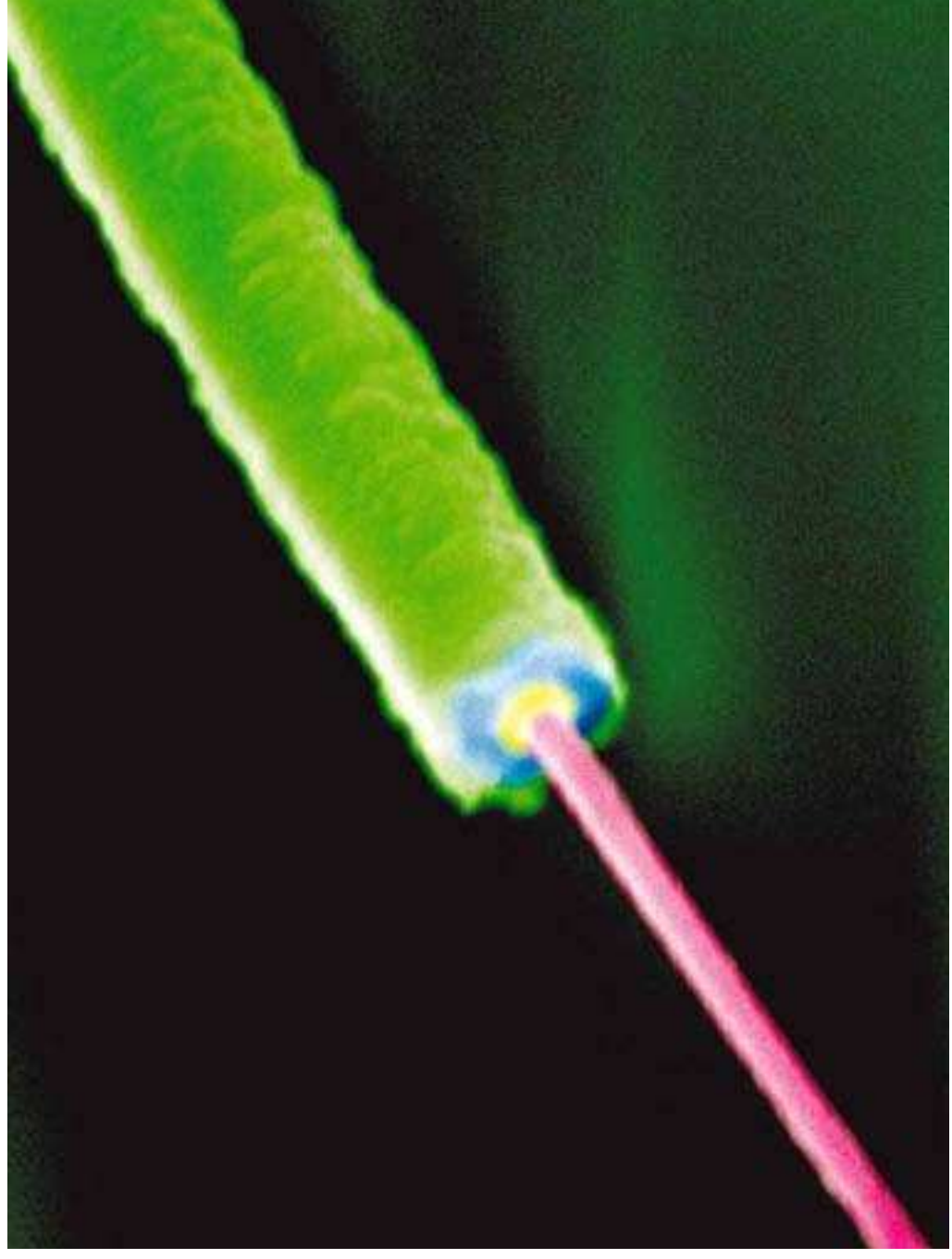
E Ink's existing displays feature microcapsules filled with charged black and white chips in a clear liquid. Switching the polarity of an electrode pushes the black or white chips up or down, forming words and images. Thanks to new "inks" it has developed that reflect 47 percent of ambient light (up from 35 to 40 percent), the company was recently able to add red, green, and blue filters to the capsules *(bottom)*, producing a prototype color display *(top)*. Meanwhile, tweaks to the particles, solution, and electronics have boosted the refresh rate from one frame per second in current displays to 30 frames per second in a "video ink" prototype. E Ink is working with partners to develop flexible transistors for use in color displays; eventually, such displays could even roll up. Commercialization is still a few years off, but "you can imagine a *USA Today* weather chart where clouds are actually moving," says Russ Wilcox, CEO of E Ink. *–David Talbot*

BOB O'CONNOR (DISPLAY); COURTESY OF E INK (FILTER)

NANOTECH

WIRE POWER

One photovoltaic wire could power a sensor; arrays could yield cheaper electricity



THIS 300-nanometer-wide silicon wire *(top)* generates electricity from sunlight. Such nanowire solar cells would initially be useful in tiny sensors, or in robots whose electronics might need built-in power. But arrays of microscopic wires could change the economics of solar power by enabling solar cells built from cheap materials such as low-grade silicon or even iron oxide—rust.

A number of such cheap materials absorb light and generate electrons, but defects in the materials usually "trap" the electrons before they can be collected. Microscopic wires, though, can be made thin enough to allow electrons to slip out easily and generate current, even if the material has defects. And the wires can be long enough to absorb plenty of photons from sunlight hitting them at an angle.

The image is colored to highlight functional layers of the nanowire, which was made in the lab of Harvard University chemist Charles Lieber. The layers are made of silicon modified in ways that give them properties useful for generating and harvesting charged particles. To make solar panels, the microscopic wires could be grown in dense arrays. The bottom image shows a cross section of a silicon-wire array fabricated in the labs of chemist Nathan Lewis and physicist Harry Atwater at Caltech. Each wire is two or three micrometers in diameter. Both groups are in the early research stages, but arranging microscopic wires in a forestlike configuration could lead to new materials that harvest sunlight cheaply and efficiently. *—Kevin Bullis*

COURTESY OF LIEBER GROUP, HARVARD (WIRE); COURTESY OF BRENDAN KAYES AND MICHAEL FILLER (ARRAY)

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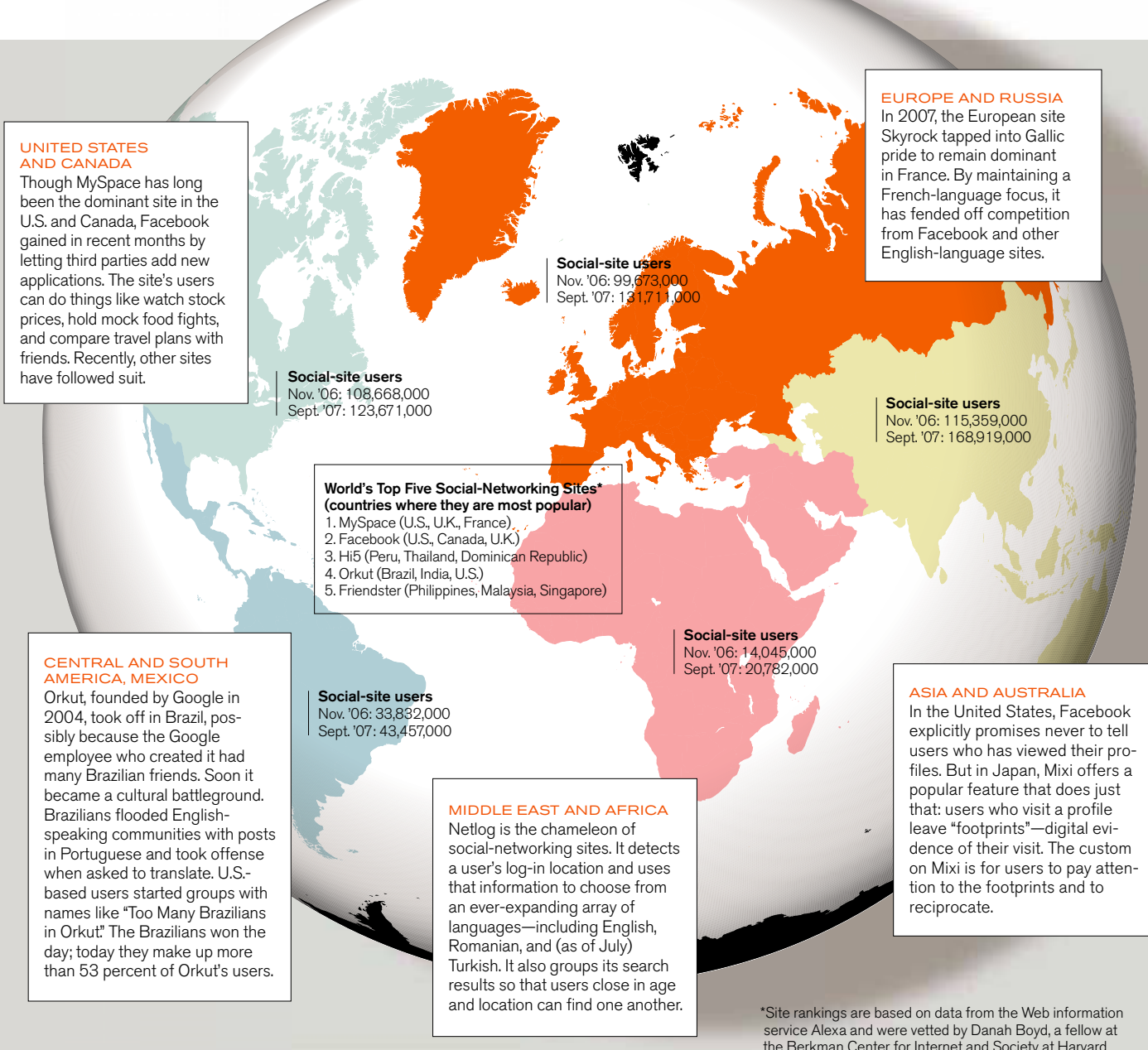


*Site rankings are based on data from the Web information service Alexa and were vetted by Danah Boyd, a fellow at the Berkman Center for Internet and Society at Harvard Law School. This list reflects only those sites devoted specifically to displaying social networks, sites Boyd calls "social-network sites." According to Boyd, two other such sites—Windows Live Spaces and the Chinese site QQ—might rank in the top five, but available data are incomplete.

INTERNET

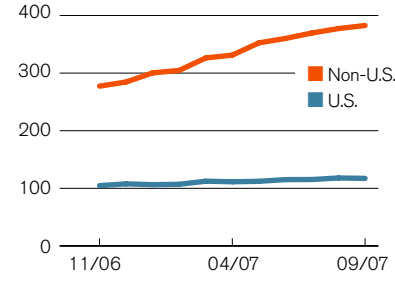
OF HI5 AND ORKUT

Social-networking sites balkanize

SINCE THE FIRST websites devoted to displaying social networks launched in the late 1990s, millions of people have connected with friends through services like MySpace, Hi5, and Cyworld. Recently, the greatest growth in the sites' popularity has occurred outside the U.S. In Asia and Australia, for example, the number of monthly users of social-networking sites (under a broad definition that includes, for example, blogging sites) jumped nearly 50 percent, to 169 million, in 10 months. Some sites have capitalized better than others: San Francisco–based Hi5, which translates pages into Spanish and Portuguese, is now the world's third-largest. A shakeout is inevitable in 2008 as patrons of many sites choose favorites. *—Erica Naone*

SOCIAL AND GLOBAL

Growth in visitors to social-networking sites, broadly defined to include blogging sites and other social sites, in millions



SITE GROWTH DATA COURTESY OF COMSCORE

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SATELLITES

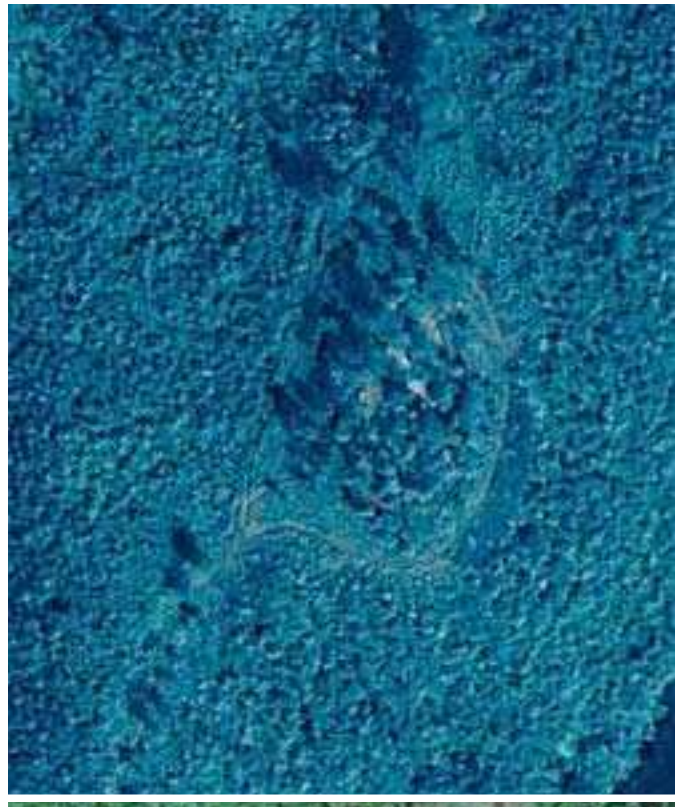
AN EYE ON DESPOTS

Images of camps and destroyed settlements bolster abuse reports

FROM DARFUR to Zimbabwe and now Burma, satellite imagery provides evidence for claims of human-rights abuses by documenting such activities as the construction of military detention centers and the razing of villages.

These "before" and "after" satellite images—ordered and analyzed by the American Association for the Advancement of Science—show the expansion of a military encampment in eastern Burma between November 11, 2000 *(top)*, and December 13, 2006 *(bottom)*; such camps support military crackdowns. The images corroborated reports from a human-rights group.

The image pairing was one of several successes for the association's project on geospatial technologies and human rights, which in recent years has helped document hundreds of human-rights violations by comparing field notes with satellite images. Among other things, the project documented the existence of forced-relocation camps where 23,700 people were said to be living, as well as the expansion of refugee camps in Thailand near the Burmese border, to which victims are fleeing. *—David Talbot*



GEOEYE (BEFORE IMAGE); DIGITALGLOBE (AFTER IMAGE); BENJAMIN SOMERS (LARS BROMLEY)

Q&A

Lars Bromley

A satellite sleuth explains how images illuminate abuses

***TR*: How easy is it to get satellite pictures in the area you need?**

Lars Bromley: Sometimes you get lucky, and a lot of times you don't. When the protests in Burma started [in October 2007], we submitted requests for imagery right away, because we wanted to see the military response. But by the time we got the imagery, everything was done.

Where are you getting these images?

Right now, there are only three satellites in orbit I can draw from, owned by DigitalGlobe, Geoeye, and ImageSat International. I can get two—four at most—images from a given location within a couple of weeks. And they don't do everything I tell them. The amount of imagery I'm buying—it's chump change.

What does the future hold for this kind of watchdog work?

There are at least two new satellites that should be operational by March or so. They can collect more images than current ones, and they have higher resolution. The best current commercial resolution is 60 centimeters. The new satellites will have a resolution of 50 centimeters. And we really do find that even a 5- or 10-centimeter improvement is significant.

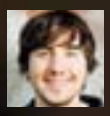
We are starting to get to the point where we have some sort of actual observation system. No matter where or when something happens in the world, we can more quickly get multiple images.*—David Talbot*

Lars Bromley heads the Geospatial Technologies and Human Rights Project at the American Association for the Advancement of Science.

Do you know a young innovator who is going to change the future of technology?

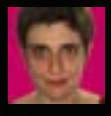
If you know someone under the age of 35 whose work in IT, biotech, medicine, materials science, energy, or transportation is making a significant impact, make a nomination NOW for the 2008 TR35 awards! Submit your nomination at TechnologyReview.com/tr35/nominate.aspx

Each year Technology Review honors 35 leading young technologists in our pages and at our annual EmTech conference. Past honorees include:



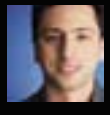
Kevin Rose
Digg.com
2007

Regina Barzilay
MIT
2005



Colin Hill
Gene Network Sciences
2004

Peidong Yang
University of California, Berkeley
2003



Sergey Brin
Google
2002

Sky Dayton
Earthlink
1999

Nominations close **February 29, 2008**

TR35

IMAGING

BRAIN CIRCUITRY, ALIGHT

Neurons in 100 hues spotlight disease, development

THIS IMAGE is one of the first to depict, in neuron-by-neuron detail, the tangled circuits that collect, process, and archive information in the mammal brain. It shows individual mouse neurons—specifically, the axons from a nerve that controls eye movements—fluorescing in different colors. Such images could help researchers better understand everything from brain development to the workings of diseases like autism and schizophrenia.

Researchers at Harvard University made the image by genetically engineering mice to carry a specialized piece of DNA that, when triggered by a particular enzyme, can randomly express any of three fluorescent proteins—yellow, red, or cyan. A single neuron contains numerous copies of this DNA segment. Once activated, each DNA piece expresses one of the proteins, giving each cell a different blend of the three colors. As a result, neurons can exhibit any of about 100 unique hues. Giving neuroscientists such a broad palette with which to paint individual brain cells will allow them to explore neural circuits as never before. "This will be an incredibly powerful tool," says Elly Nedivi, a neuroscientist at MIT who is not involved in the research. "It will open up huge opportunities in terms of looking at neural connectivity." Scientists will probably use the engineered mice to study disease and the neural connections and disconnections that occur as young brains develop. *—Emily Singer*

COURTESY OF JEAN LIVET

SXSW INTERACTIVE FESTIVAL: CONNECT, DISCOVER, INSPIRE

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Opening Remarks by Henry Jenkins on Saturday, March 8

The Co-Director of the Comparative Media Studies Program at MIT, Jenkins has also authored numerous books including "Convergence Culture: Where Old and New Media Collide" and "Fans, Bloggers and Gamers: Exploring Participatory Culture."

Confirmed speakers include **Michele Bowman** (Global Foresight Associates), **Jim Coudal** (Coudal Partners), **Natalie Zee Drieu** (Craft Magazine), **Tim Ferriss** (Author), **Jason Fried** (37signals), **John Gruber** (Daring Fireball), **Matt Mullenweg** (WordPress), **Annalee Newitz** (Techsploitation) and **Joshua Schachter** (del.icio.us).

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STARTUP

YOUR FUTURE, ON A CHIP

Navigenics promises genomic testing and genetic counseling

Dietrich Stephan (left) and David Agus

NAVIGENICS, of Redwood Shores, CA, is developing a genetic test to help customers assess and respond to their risks of contracting numerous illnesses, including Alzheimer's, type 2 diabetes, rheumatoid arthritis, and breast cancer. The genome-wide scan targets 20 diseases so far.

The company says that this year it will begin offering the test directly to consumers for $2,500, joining competitors deCode Genetics of Iceland and 23andMe of Mountain View, CA, both of which recently began offering personal genetic tests for under $1,000. Navigenics also says that it plans to follow up customers' test results with extensive interpretation from on-staff genetic counselors.

A client will send a saliva sample to Navigenics, which will use a genetic array from Affymetrix, capable of detecting 1 million specific genetic variations, to scour the DNA in the sample for genetic misspellings. Proprietary software will then spit out a report that compares the client's disease risks with those of the general population; explains the extent to which environmental and genetic factors contribute to the diseases; and suggests further screening measures and early interventions, ranked by the level of clinical evidence supporting them.

"If you knew 50 years in advance that you were at increased risk for Alzheimer's disease, you could lower your cholesterol and keep physically and mentally fit," says Navigenics cofounder Dietrich Stephan, the company's chief scientific officer. "When early signs of Alzheimer's start, you may be better equipped to start on cutting-edge compounds that might push the onset out by decades."

Greg Feero, chief of genomic health care at the National Human Genome Research Institute, is less enthusiastic, warning that such tests have not proved their usefulness and could burden patients with worry and uncertainty. He says it's far from clear what probabilities mean for a given individual or whether proposed interventions would be effective. He notes, too, that some patients might accept bad test results fatalistically instead of pursuing such interventions.

Still, Navigenics CEO Mari Baker sees a ready market, pointing out that "millions and millions" of U.S. residents already spend thousands of dollars every year on discretionary health purchases. But she admits that nobody knows how many people will order genetic tests. "It's a brand-new industry," she says. —*Emily Singer*

NAVIGENICS

URL: www.navigenics.com

Location: Redwood Shores, CA

Product: Health Compass, a report that calculates disease probabilities on the basis of genomic and other risk factors

Founders: David Agus, director of the Spielberg Family Center for Applied Proteomics at Cedars-Sinai Medical Center; Dietrich Stephan, chairman of the National Institutes of Health Neuroscience Microarray Consortium

CEO: Mari Baker, former executive in residence at Kleiner Perkins Caufield and Byers and former president of BabyCenter

Number of employees: 40

Funding amount: $25 Million

Funders: Kleiner Perkins Caufield and Byers; Mohr Davidow Ventures; Sequoia Capital

Partners: Affymetrix, Cleveland Clinic, Georgetown University, Mayo Clinic, Scripps Health, Partners HealthCare, Medscape

SAUL BROMBERGER AND SANDRA HOOVER

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TO MARKET

PROCESSORS

MOORE'S LAW HANGS ON

Each of the 820 million transistors on Intel's three-gigahertz quad-core processor is only 45 nanometers across, 30 percent smaller than those on previous commercial chips. Smaller transistors need thinner layers of electrical insulation, or dielectrics—which is hard to achieve with the traditional insulator, silicon dioxide. With its 45-nanometer chips, however, Intel has begun using a new insulator, hafnium oxide. The quad-core processor *(shown here)* will probably be used in network servers; a smaller, dual-core processor could turn up in high-end desktop computers.

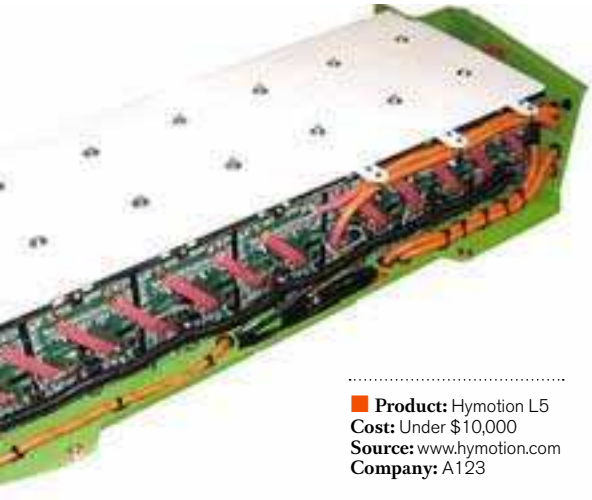
Product: Intel Core2 Extreme quad-core processor **Cost:** $999 in quantities of 1,000 **Source:** www.intel.com/products/processor/core2xe **Company:** Intel

BRUCE PETERSON

BATTERIES

DO-IT-YOURSELF PLUG-INS

HYBRID CARS that can recharge their batteries by plugging into electrical outlets could enable nearly gas-free commutes and even provide extra storage on the electrical grid, but they're not yet commercially available. This year, however, Toyota Prius owners will be able to turn their cars into plug-ins by installing a new battery pack from A123 Systems, a company based in Watertown, MA. The pack stores five kilowatt-hours of electricity and uses a new nanostructured electrode material that makes high-capacity lithium-ion batteries safe enough for automotive use.



Product: Hymotion L5
Cost: Under $10,000
Source: www.hymotion.com
Company: A123

DISPLAYS

FIRST OLED TV

DISPLAYS THAT use organic light-emitting diodes (OLEDs) are more vivid than liquid-crystal displays, have much faster refresh rates, and draw less power, but so far, manufacturing difficulties have limited them to small sizes fit only for handheld devices. On December 1, and only in Japan, Sony released the world's first OLED television, featuring an 11-inch panel with a layer of light-emitting organic material just several hundred nanometers thick. Initially, Sony plans to manufacture 2,000 of the TVs per month.

Product: XEL-1 **Cost:** 200,000 yen (about $1,800) **Source:** www.sony.net/SonyInfo/News/Press/200710/07-1001E **Company:** Sony

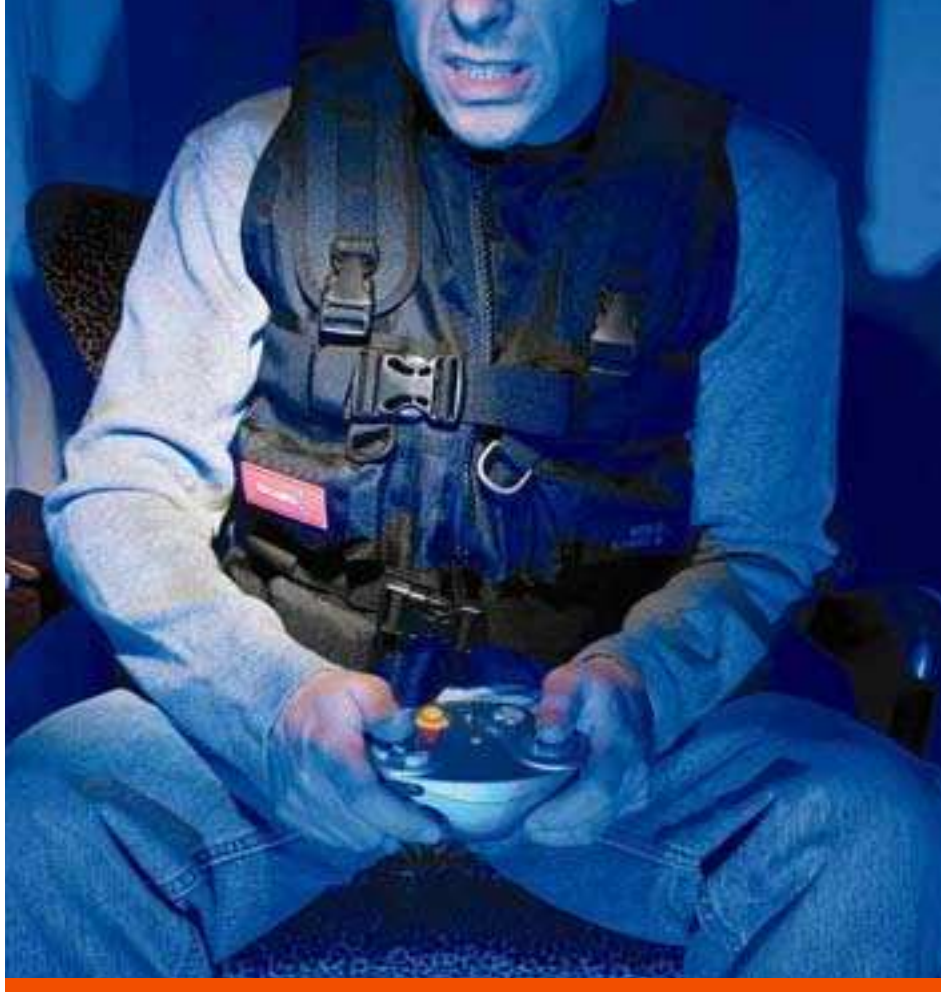
INTERFACES

Tabletop Multitouch Display

THE APPLE iPhone heralded the age of the multitouch display. Now Microsoft has gotten into the act with the Surface, a table-sized computer with a horizontal 30-inch screen. An infrared emitter inside the Surface bounces light off objects touching the screen, fingertips included; cameras register the objects' locations. This spring, the Surface will appear in stores and hotels, where it will let people compare products or search for nearby events.

Product: Surface **Cost:** $5,000 to $10,000, depending on volume and service contract
Source: www.microsoft.com/surface **Company:** Microsoft

COURTESY OF SONY (TV); COURTESY OF A123 (PLUG-INS); COURTESY OF MICROSOFT (MULTITOUCH)



HAPTICS

PNEUMATIC GAMING VEST

THE 3RD SPACE haptic vest for video-game players uses eight embedded pneumatic cells to suggest the sensation of a finger tap, G-forces, or even a bullet's impact. The vest is based on a more complicated medical device designed by vascular surgeon Mark Ombrellaro, TN Games' CEO, which lets doctors examine patients by touch from a distance. The blows the vest delivers are painless, but Ombrellaro says some gamers have asked that they be intensified.

Product: 3rd Space vest **Cost:** $189 **Source:** www.tngames.com **Company:** TN Games

GENOMICS

Single-Molecule Gene Sequencer

MOST GENE sequencers require thousands of copies of a DNA strand. But Helicos BioSciences' new system can sequence a single molecule, simplifying sample preparation and decreasing cost. It can also gauge gene activity by counting messenger RNAs, molecules that help translate genes into proteins; its ability to rapidly determine chemicals' effects on gene activity could speed drug development. With improvements to just its reagent kits, the system could ultimately deliver the $1,000 genome.

Product: HeliScope Genetic Analysis System **Cost:** $1,350,000; single-use reagent kit: $18,000
Source: www.helicosbio.com **Company:** Helicos BioSciences

SENSORS

CONCUSSION-SENSING HELMET

THE NEWEST football helmet from Riddell, a sporting-equipment manufacturer in Rosemont, IL, is equipped with sensors that measure the magnitude, location, and direction of blows to a player's head. The collected data is wirelessly transmitted to a computer—which could be stationed on the sideline—and analyzed with a Web-based application to indicate the likelihood that a player has suffered a concussion. The University of Missouri and other NCAA football teams have already ordered the helmet.

Product: Revolution IQ Hits
Cost: $999
Source: www.riddell.com
Company: Riddell

COURTESY OF HELICOS (SEQUENCER); CHRISTOPHER HARTING (VEST); COURTESY OF RIDDELL (HELMET)

PHOTONICS

SILICON OPTICS

PHOTONIC devices—chips that send and receive data-carrying light signals—are usually made from exotic, costly semiconducting materials. Devices made from silicon would be orders of magnitude cheaper and could drastically reduce the cost of bandwidth. Now Luxtera, in Carlsbad, CA, is offering the first commercial optical cable made with silicon photonics. Intended for use in data centers, the cable can transmit 40 gigabits of data per second but costs no more than some existing 20-gigabit-per-second optical cables.

Product: Blazar cable
Cost: Less than $1,000 for a 300-meter, 40-gigabit cable
Source: www.luxtera.com/content/view/35/37
Company: Luxtera

WIRELESS

AUTOMATIC PHOTO UPLOADS

DIGITAL CAMERAS have become so simple that many people end up taking more pictures than they have time to upload to their computers. Eye-Fi, a startup in Mountain View, CA, hopes to change that with its new two-gigabyte secure-digital memory card, which turns any compatible camera into a wireless transmitter. When a camera containing the card comes within range of a preselected Wi-Fi network, the card automatically uploads its contents to a local PC or to a designated photo-sharing site on the Internet.

Product: Eye-Fi Card **Cost:** $99.99 **Source:** www.eye.fi **Company:** Eye-Fi

INTERFACES

HANDS-FREE IPOD

DON'T LIKE what's playing on the car stereo? Just tell your iPod to jump to another song. A new in-car system from Ford and Microsoft connects to music players through a dashboard USB port and to cell phones via Bluetooth, letting the driver control both devices with voice commands. The system knows where to look for song and address-book data in a wide range of devices and translates it into phonetic codes intelligible to voice recognition software.

Product: Sync **Cost:** Standard or a $395 option on select 2008 Fords
Source: www.syncmyride.com **Company:** Ford, Microsoft

THE WEB

The Semantic Web Goes Mainstream

TWINE, a new Web-based application from San Francisco startup Radar Networks, helps people keep track of personal data, including e-mails, documents, photos, videos, and visited Web pages. But its artificial-intelligence algorithms also help categorize that data, sometimes finding surprising connections in disparate content. It is one of the first commercial applications to take advantage of standards developed by the World Wide Web Consortium for the Semantic Web, an envisioned network that will automatically classify and sort information.

Product: Twine
Cost: Free
Source: www.twine.com
Company: Radar Networks

CHRISTOPHER HARTING (EYE-FI, CABLE); COURTESY OF FORD (HANDS-FREE)


Imagination becoming
REALITY in
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VIMS
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ROADS
ECONOMIC DEVELOPMENT ALLIANCE

Q&A

PETER NORVIG

The evolution of Web search

As director of research at Google, Peter Norvig is intimately involved in the attempt to manage the world's information. He's a good match for the job, having spent much of his life thinking about how computers think and making them do it more efficiently. An expert on artificial intelligence, he has taught at universities, held research jobs in the corporate world and at NASA, and cowritten the influential textbook *AI: A Modern Approach*.

Norvig came to Google in 2001 as the director of search quality; he assumed his current position four years later. In that role, he oversees about 100 computer scientists as they work on projects as diverse as medical records management and machine translation. An untold number of Google servers housing the searchable Web provide them with a test bed. He says Google is structured to ensure that researchers are not sequestered from the rest of the company. "The main allegiance they have is to the product they're working on," he says.

When Norvig arrived in Mountain View, Web search was simply about serving up the pages most relevant to a given query. But as the Web has grown, so has people's need to filter information quickly. Norvig recently spoke with *Technology Review's* information technology editor, Kate Greene, about what's next for Web search.

***TR*: Google has many innovative products, but the look and feel of Web search hasn't changed much in 10 years. Why?**

Norvig: We've hit on something that people mostly liked. We weren't the first to do it. Go back to Excite and the search engines before: you have a box, and you get a list of 10 results, with a little bit of information accompanying each result. We've just stuck with that.

What has changed?

The scale. There's probably a thousand times more information. It used to be just Web pages; now it's video, pictures, blogs, and all sorts of media and formats. Also, the immediacy has changed. When I started, we were updating the index once a month. We thought of it as a library catalogue, a long-term thing. Now we're seeing it more as up-to-the-minute media. When news breaks, you want to be able to read it in minutes, not in days, weeks, or months.

You claim that Google's accuracy is pretty good. How do you know how good it is, and how do you make it better?

We test it in lots of ways. At the grossest level, we track what users are clicking on. If they click on the number-one result, and then they're done, that probably means they got what they wanted. If they're scrolling down, page after page, and reformulating the query, then we know the results aren't what they wanted. Another way we do it is to randomly select specific queries and hire people to say how good our results are. These are just contractors that we hire who give their judgment. We train them on how to identify spam and other bad sites, and then we record their judgments and track against that. It's more of a gold standard because it's someone giving a real opinion, but of course, since there's a human in the loop, we can't afford to do as much of it. We also invite people into the labs, or sometimes we go into homes and observe them as they do searches. It provides insight into what people are having difficulty with.

Companies such as Ask and Powerset are betting that the future is in natural-language search, which lets people use real, useful sentences instead of potentially ambiguous keywords. What is Google doing with natural language?

We think what's important about natural language is the mapping of words onto the concepts that users are looking for. But we don't think it's a big advance to be able to type something as a question as opposed to keywords. Typing "What is the capital of France?" won't get you better results than typing "capital of France." But *understanding* how words go together is important. To give some examples, "New York" is different from "York," but "Vegas" is the same as "Las Vegas," and "Jersey" may or may not be the same as "New Jersey." *That's* a natural-language aspect that we're focusing on. Most of what we do is at the word and phrase level; we're not concentrating on the sentence. We think it's important to get the right results rather than change the interface.

How much will Google search become personalized to individual users?

We're doing some of that in various places. One good example is in news personalization, where we give recommendations for news articles. There, it's easier to do than in larger Web databases, because there's a limited number of news stories. We track what news stories you look at, and we compare it to other people. And that seems to work out well. It's harder to apply it to something as vast as the whole Web, but we're starting with the easy parts.

Where do you see Google search in two to five years?

You'll see integration of various kinds of content. We're getting into speech recognition and all the kinds of interfaces on phones, where you have a tiny screen and awkward keyboard. You'll see that gaining in importance. You'll see integration of our various properties. We used to put the onus on the user and ask them if they wanted Web search or image search or video search. Now we're trying to solve that for them and serve up the results in a way that makes sense.

Photograph by HOWARD CAO

PHOTO ESSAY

THE BUILDING, DIGITALLY REMASTERED

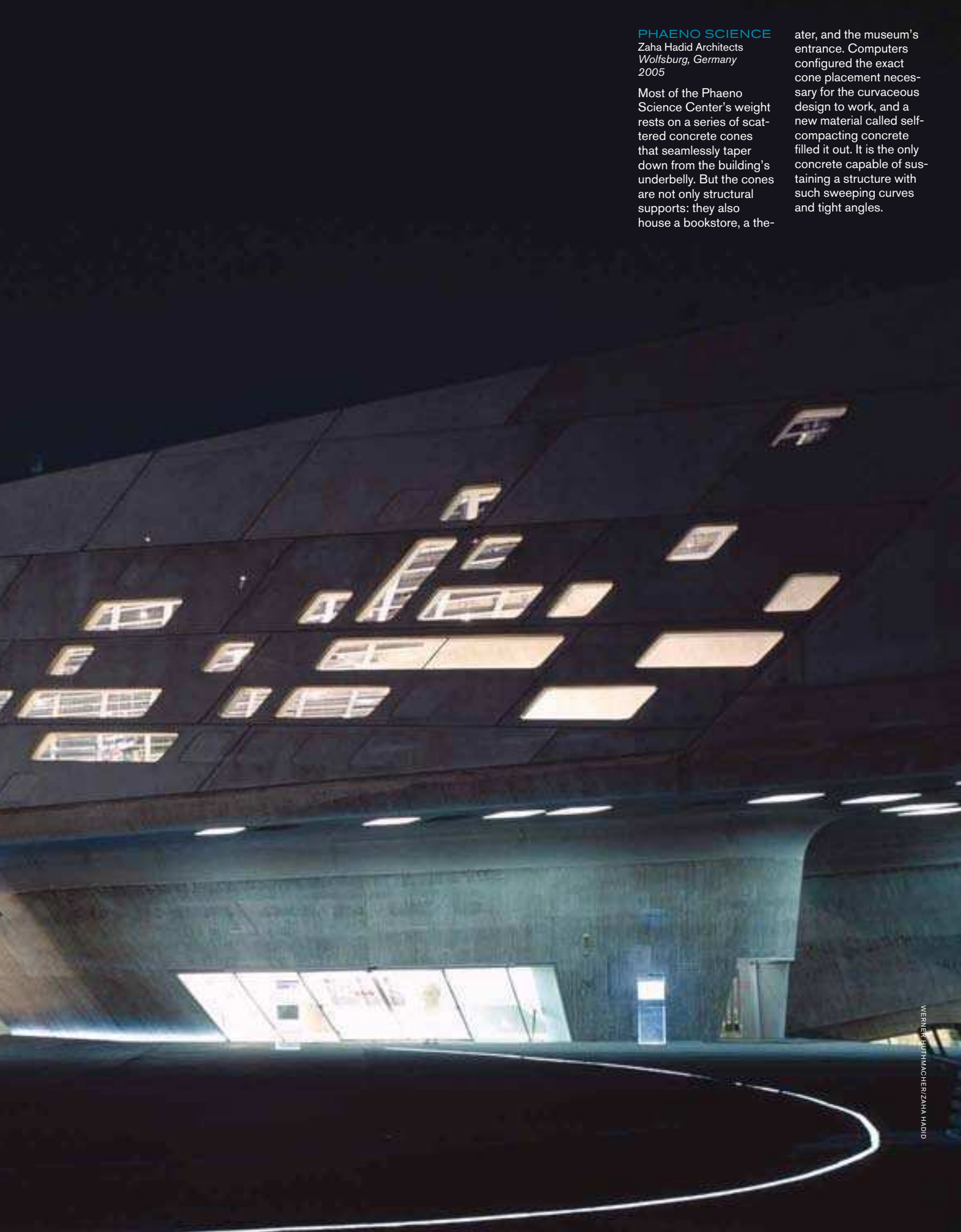
Fifteen years ago, it would have been difficult—and in some cases impossible—to engineer the buildings in these pages. Now powerful computer-assisted design and manufacturing techniques let architects build according to wholly new geometries. In this era, the rectilinear glass box has become a quaint relic of the predigital past.

By MICHAEL PATRICK GIBSON

PHAENO SCIENCE

Zaha Hadid Architects
Wolfsburg, Germany
2005

Most of the Phaeno Science Center's weight rests on a series of scattered concrete cones that seamlessly taper down from the building's underbelly. But the cones are not only structural supports: they also house a bookstore, a theater, and the museum's entrance. Computers configured the exact cone placement necessary for the curvaceous design to work, and a new material called self-compacting concrete filled it out. It is the only concrete capable of sustaining a structure with such sweeping curves and tight angles.



WERNER HUTHMACHER/ZAHA HADID

HEARST TOWER

Foster + Partners
New York, NY
2006

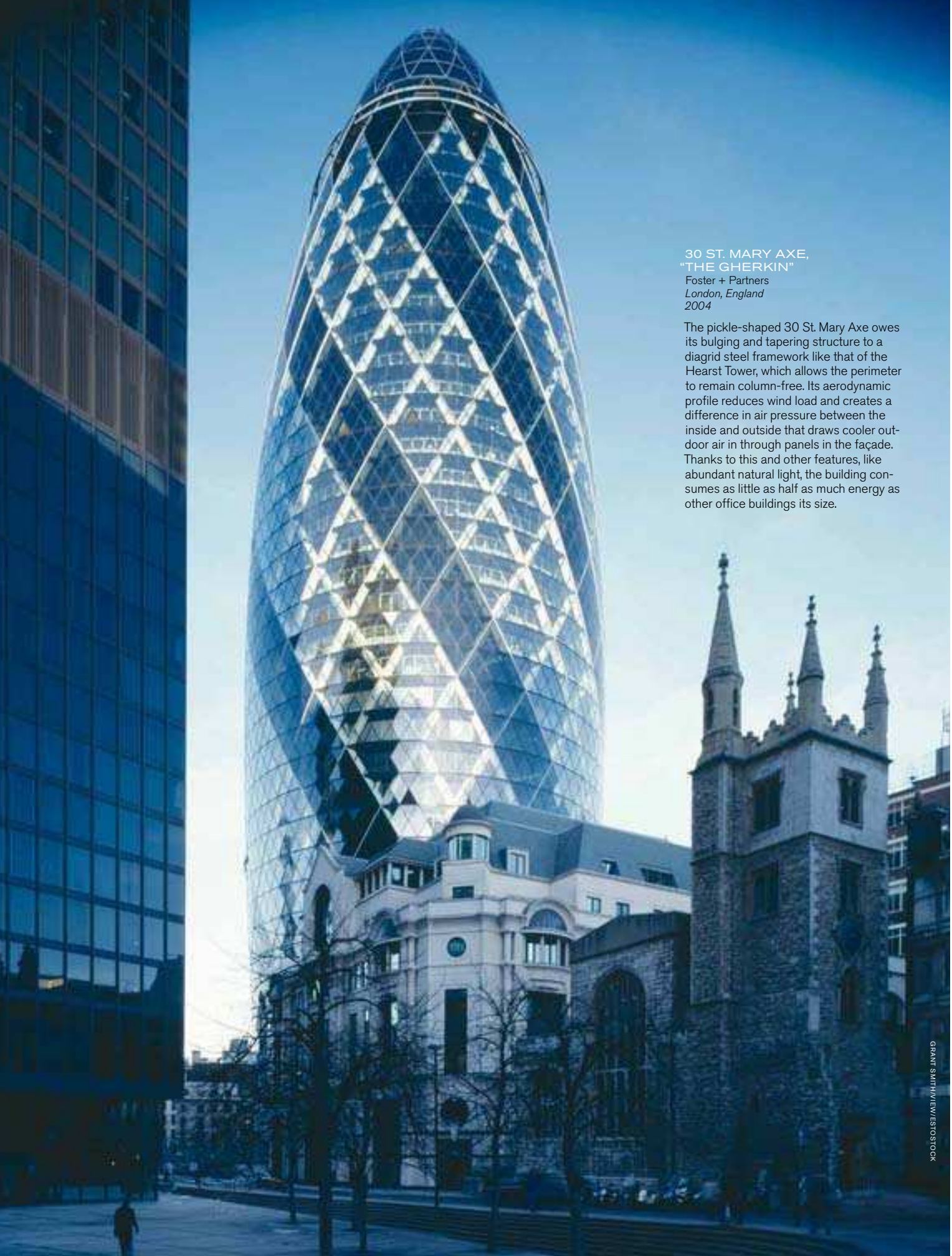
The Hearst Tower's triangular frames, known as diagrids, eliminate the need for any vertical steel columns around the building's perimeter. It is the first building in North America to feature this gravity-defying technique. So efficient is Foster's design that the building uses 20 percent less steel tonnage than a conventional building of its size.

TURNING TORSO

Santiago Calatrava
Malmö, Sweden
2005

From top to bottom, Calatrava's anthropomorphic apartment tower twists 90°. The building was constructed by stacking nine warped cubes, each five stories high, on top of each other; each cube rotates about 11° from the one below it. An external spine buttresses the twist, mimicking a human spinal column, while an exoskeleton sprouts from the spine to provide wind resistance and damp the building's vibrations.

CHUCK CHOI/ARCAID/CORBIS (HEARST); PATRICK PERSSON/EPA/CORBIS (TORSO)

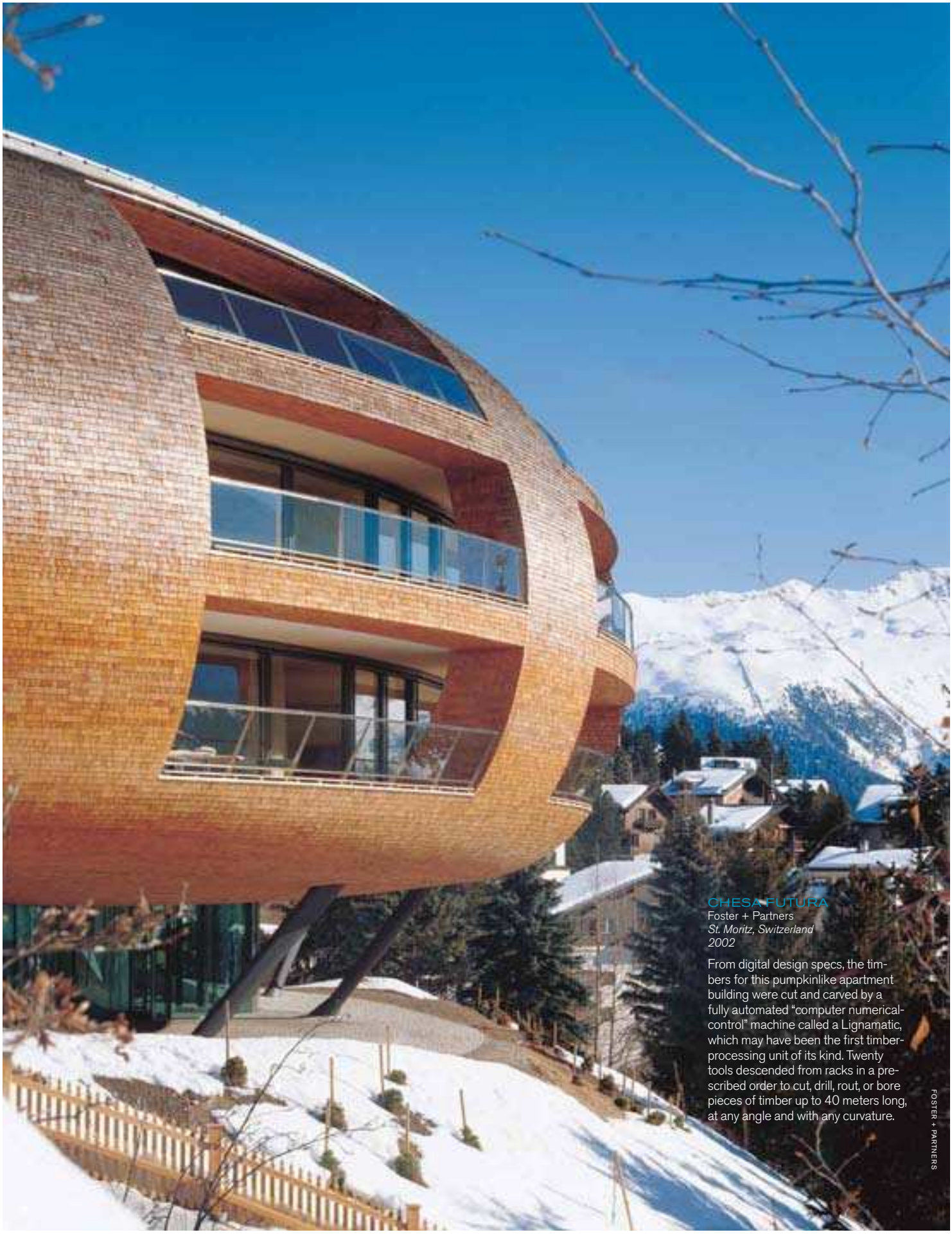


30 ST. MARY AXE, "THE GHERKIN"

Foster + Partners
London, England
2004

The pickle-shaped 30 St. Mary Axe owes its bulging and tapering structure to a diagrid steel framework like that of the Hearst Tower, which allows the perimeter to remain column-free. Its aerodynamic profile reduces wind load and creates a difference in air pressure between the inside and outside that draws cooler outdoor air in through panels in the façade. Thanks to this and other features, like abundant natural light, the building consumes as little as half as much energy as other office buildings its size.

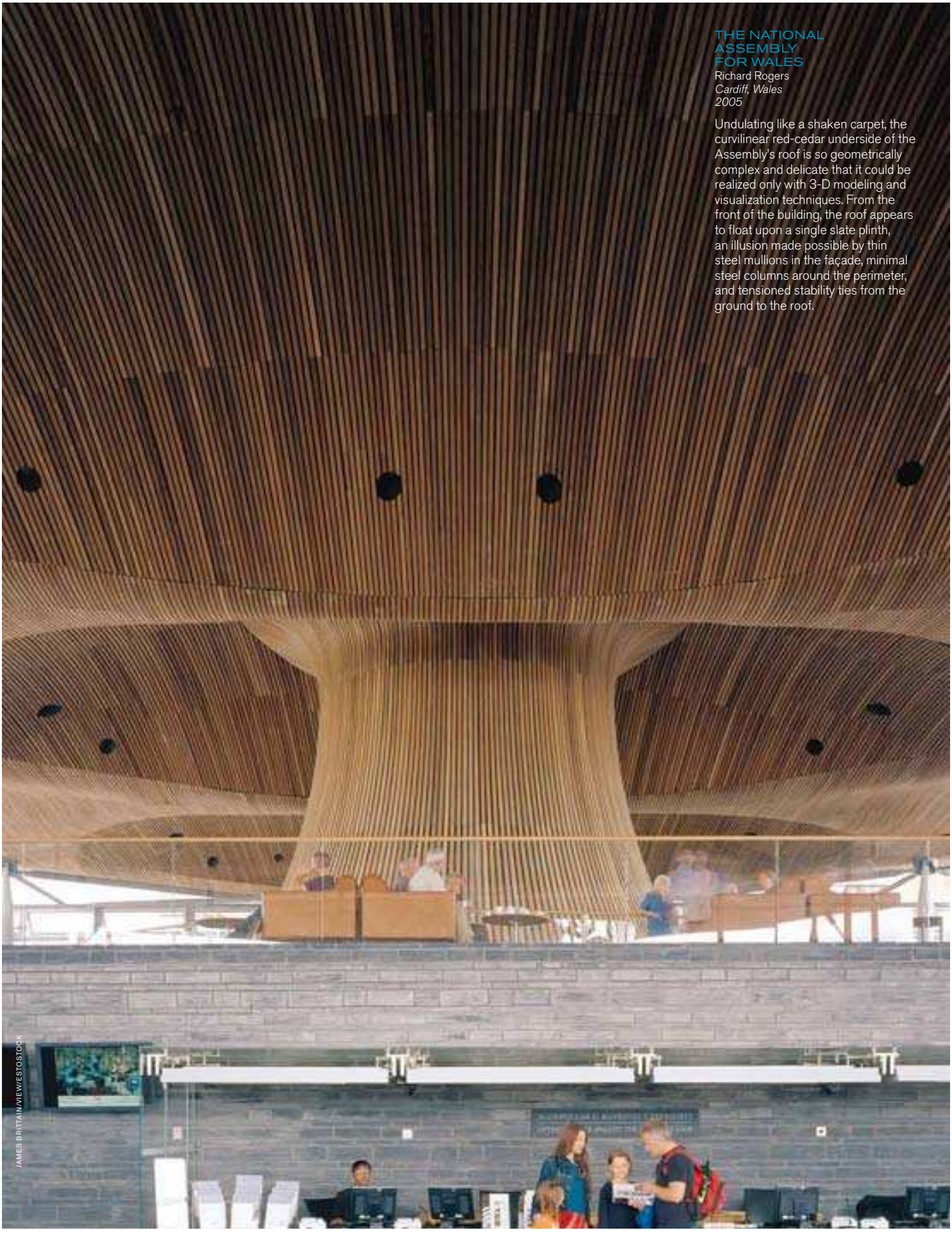
GRANT SMITH/VIEW/ESTOSTOCK



CHESA FUTURA
Foster + Partners
St. Moritz, Switzerland
2002

From digital design specs, the timbers for this pumpkinlike apartment building were cut and carved by a fully automated "computer numerical-control" machine called a Lignamatic, which may have been the first timber-processing unit of its kind. Twenty tools descended from racks in a prescribed order to cut, drill, rout, or bore pieces of timber up to 40 meters long, at any angle and with any curvature.

FOSTER + PARTNERS



THE NATIONAL ASSEMBLY FOR WALES

Richard Rogers
Cardiff, Wales
2005

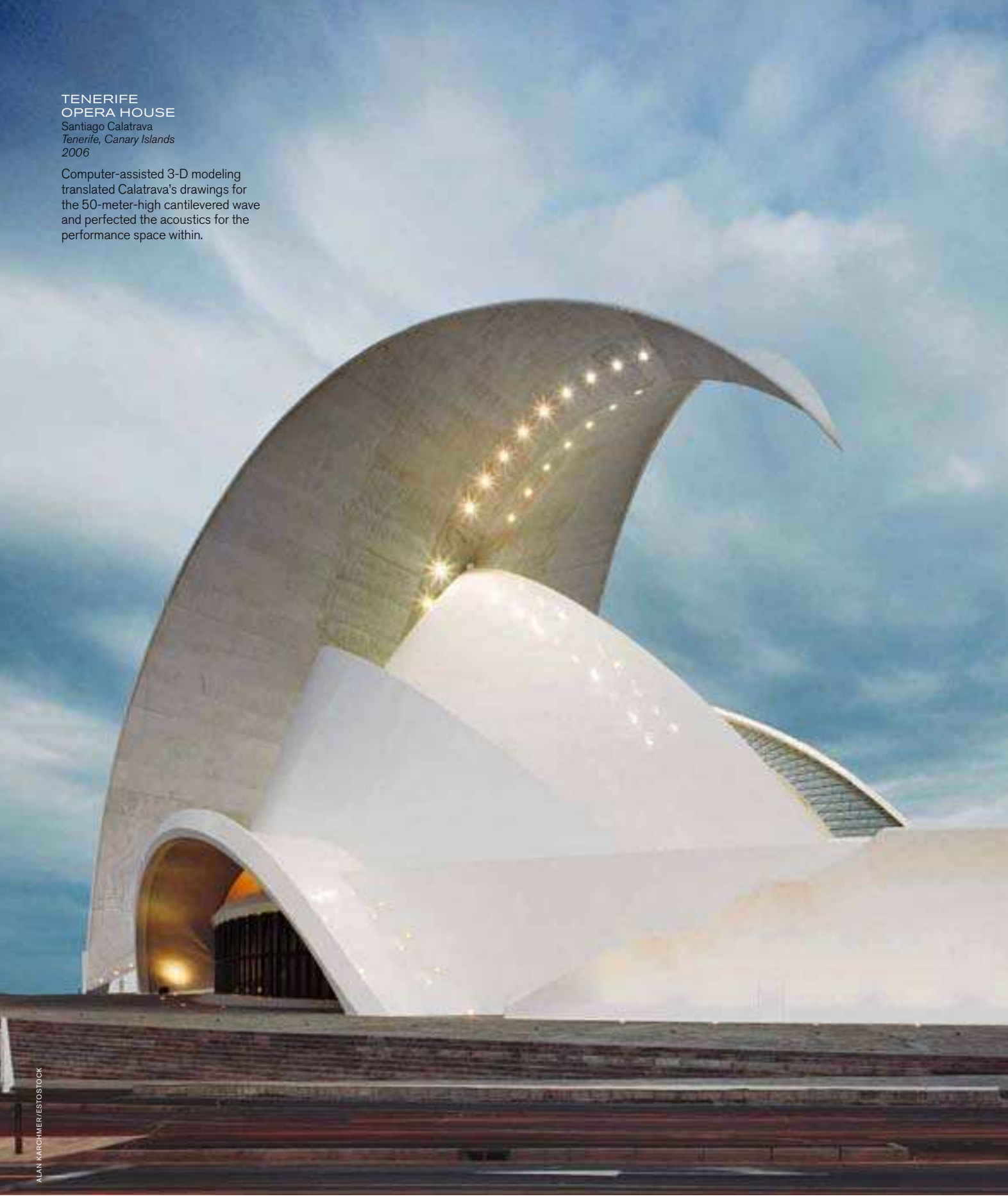
Undulating like a shaken carpet, the curvilinear red-cedar underside of the Assembly's roof is so geometrically complex and delicate that it could be realized only with 3-D modeling and visualization techniques. From the front of the building, the roof appears to float upon a single slate plinth, an illusion made possible by thin steel mullions in the façade, minimal steel columns around the perimeter, and tensioned stability ties from the ground to the roof.

JAMES BRITTAIN/VIEWSTOSTOCK

TENERIFE OPERA HOUSE

Santiago Calatrava
Tenerife, Canary Islands
2006

Computer-assisted 3-D modeling translated Calatrava's drawings for the 50-meter-high cantilevered wave and perfected the acoustics for the performance space within.



ALAN KARCHMER/ESTOSTOCK

SIMON GLYNN/GALINSKY.COM (PIER); RALPH RICHTER/ARCHENOVA/ESTOSTOCK (HOUSE)

www See more photographs of these buildings: **technologyreview.com/architecture**

DANCING HOUSE

Frank Gehry
Prague, Czech Republic
1996

With hourglass bends and tapering profiles, each of the two towers—dubbed Fred and Ginger—displays the computer-generated irregular geometry that has become Gehry's signature.

HYDRA-PIER

Asymptote
Haarlemmermeer, The Netherlands
2002

Designed with the help of software used in aeronautics, Hydra-Pier features two "wings" that slope downward. Water cascades over them and runs off the sides as it descends, creating a watery alleyway through which visitors enter.

MAKING ETHANOL FROM CORN IS EXPENSIVE. BETTER BIOFUELS ARE YEARS AWAY FROM THE GAS TANK. FARMERS ARE RELUCTANT TO CHANGE THEIR PRACTICES. BUT DO WE REALLY HAVE ANY ALTERNATIVE TO BIOFUELS?

The Price of Biofuels

By DAVID ROTMAN

The irrational exuberance over ethanol that swept through the American corn belt over the last few years has given way to a dreary hangover, especially among those who invested heavily in the sprawling production facilities now dotting the rural landscape. It's the Midwest's version of the tech bubble, and in some ways, it is remarkably familiar: overeager investors enamored of a technology's seemingly unlimited potential ignore what, at least in retrospect, are obvious economic realities.

More than a hundred biofuel factories, clustered largely in the corn-growing states of Iowa, Minnesota, Illinois, Indiana, South Dakota, and Nebraska, will produce 6.4 billion gallons of ethanol this year, and another 74 facilities are under construction. Just 18 months ago, they were cash cows, churning out high-priced ethanol from low-priced corn, raising hopes of "energy independence" among politicians, and capturing the attention—and money—of venture capitalists from both the East and West Coasts.

Now ethanol producers are struggling, and many are losing money. The price of a bushel of corn rose to record highs during the year, exceeding $4.00 last winter before falling back to around $3.50 in the summer, then rebounding this fall to near $4.00 again. At the same time, ethanol prices plummeted as the market for the alternative fuel, which is still used mainly as an additive to gasoline, became saturated. In the face of these two trends, profit margins vanished.

The doldrums of the ethanol market reflect the predictable boom-and-bust cycle of any commodity: high prices drive increased production, and soon the market is oversupplied, causing prices to crash. But the large-scale use of corn-derived ethanol as a transportation fuel has economic problems all its own. Even though crude oil is at near record prices, and companies that use ethanol in their gasoline receive a federal tax credit of 51 cents per gallon, ethanol struggles to compete economically. And with limited infrastructure in place to distribute and sell the biofuel, demand will remain uncertain for the foreseeable future.

More alarming, the boom in ethanol production is driving up the price of food. Of the record 93 million acres of corn planted in the United States in 2007, about 20 percent went to ethanol. Since most of the rest is used to feed animals, the prices of beef, milk, poultry, and pork are all affected by increases in the cost of corn. The international Organization for Economic Coöperation and Development (OECD) recently warned that the "rapid growth of the biofuels industry" could bring about fundamental shifts in agricultural markets worldwide and could even "cause food shortages."

All this comes at a time when the need for alternatives to petroleum-based transportation fuels is becoming urgent. At press time, the price of crude oil was near $90 a barrel. And worries about the impact of greenhouse-gas emissions from the roughly 142 billion gallons of gasoline used every year in the United States are deepening. Expanded use of biofuels is central to the federal government's long-term energy strategy. In his State of the Union speech on January 23, 2007, President Bush set the goal of producing 35 billion gallons of renewable and alternative fuels by 2017, citing the need for independence from foreign oil. The U.S. Department of Energy has set the similar goal of replacing 30 percent of gasoline use with biofuel use by 2030.

Hitting both targets, however, will require significant technological breakthroughs. In the United States, for now, ethanol means the corn-derived version. (Brazilian producers were expected to make 4.97 billion gallons of ethanol in 2007, mostly from sugarcane; but that semitropical crop is agriculturally viable in only a few parts of the United States.) Even proponents of corn ethanol say that its production levels cannot go much higher than around 15 billion gallons a year, which falls far short of Bush's goal.

STEVE HEBERT/POLARIS


For Flexible Fuel Vehicles Only
E85
85% Ethanol
E-85
3
NO SMOKING
STOP ENGINE
Petro-Card 24
E85
85% Ethanol

While President Bush and other advocates of biofuels have often called for ethanol to be made from alternative feedstocks such as switchgrass—a plant native to the U.S. prairie states, where it grows widely—the required technology is, according to most estimates, at least four to five years from commercial viability. Meanwhile, advanced biological techniques for creating novel organisms that produce other biofuels, such as hydrocarbons, are still in the lab. So far, researchers are making quantities that wouldn't even fill the tank of a large SUV.

The economic woes and market limitations of corn ethanol are a painful reminder of the immense difficulties facing developers of new biofuels. "The bottom line is that you're going to have to make fuel cheap," says Frances Arnold, a professor of chemical engineering and biochemistry at Caltech. "We can all make a little bit of something. But you have got to make a lot of it, and you have got to make it cheaply. The problem is so huge that your technology has to scale up and do it at a price that is competitive. Everyone is going to be competing on price alone."

"We can all make a little bit of something. But you have got to make a lot of it, and you have got to make it cheaply. The problem is so huge that your technology has to scale up and do it at a price that is competitive. Everyone is going to be competing on price alone."

CORN BLIGHT

There may be no better place to get a realistic appraisal of biofuels than the Department of Applied Economics at the University of Minnesota. The large campus housing the department and the rest of the university's school of agriculture lies on a low hill in a quiet St. Paul neighborhood. Acres of fields where experiments are conducted spread out from the edge of the university. Nearby are the grounds of the Minnesota State Fair, a 12-day event that draws more than a million and a half visitors at the end of the summer.

The state is the fourth-largest producer of corn in the U.S., and much of its economy, even its culture, is intimately tied to the crop. The run-up of corn prices has been a boon for Minnesota's rural agricultural communities. And the governor and other state politicians have strongly pushed the use of ethanol as a transportation fuel. Still, you won't find much cheerleading for corn ethanol in the plain brick building that houses the department.

In his orderly office with its neat stacks of technical papers and farm reports, Vernon Eidman, an emeritus professor of agricultural economics, combines the authority of a scholar with the sternness of a Midwestern banker. "We could see this coming," he says, describing the current market plight of the ethanol producers. "It's not like [producers] didn't know it was coming. At least, they should have known it." In 2006 they "made profits like they never had before," Eidman says. "And that's a major factor that led to this tremendous buildup."

The numbers speak for themselves. Eidman's calculations show what it costs, given varying prices of corn, for a new, moderate-size facility to produce ethanol. At $4.00 a bushel of corn, ethanol production costs $1.70 a gallon; to gain a 12 percent return on equity, the producers need to sell ethanol at $1.83 a gallon. Then Eidman shows his figures for the prices that petroleum companies are paying when they buy ethanol to blend with their gasoline: this December, prices were about $1.90 a gallon, and bids for 2008 range between $1.75 and a $1.80 a gallon. In other words, the profit margins for ethanol producers are extremely tight. To make matters worse, Eidman says, production capacity, which was around 5.4 billion gallons at the beginning of 2007, is expected to reach 12.5 billion gallons by 2010.

While swelling ethanol production has led to worries about oversupply, the other side of the market equation is actually a cause for greater concern: the future demand for ethanol fuel is by no means certain. In a few parts of the country, particularly in the corn-belt states, drivers can buy fuel that's 85 percent ethanol. But for the most part, petroleum companies use ethanol at a concentration of 10 percent, to increase the oxygen content of their gasoline. Not only is such a market limited, but the 10-percent-ethanol blend delivers slightly reduced gas mileage, potentially damping consumer appetite for the fuel.

It is not just the short-term economics of ethanol that concern agricultural experts. They also warn that corn-derived ethanol is not the "green fuel" its advocates have described. That's because making ethanol takes a lot of energy, both to grow the corn and, even more important, to run the fermentation facilities that turn the sugar gleaned from the corn kernels into the alcohol that's used as fuel. Exactly how much energy it takes has been the subject of intense academic debate in various journals during the last few years.

According to calculations done by Minnesota researchers, 54 percent of the total energy represented by a gallon of ethanol is offset by the energy required to process the fuel; another 24 percent is offset by the energy required to grow the corn. While about 25 percent more energy is squeezed out of the biofuel than is used to produce it, other fuels yield much bigger gains, says Stephen Polasky, a professor of ecological and environmental economics at Minnesota. Making ethanol is "not a cheap process," he says. "From my perspective, the biggest problem [with

STEVE HEBERT/POLARIS

corn ethanol] is just the straight-out economics and the costs. The energy input/output is not very good."

The high energy requirements of ethanol production mean that using ethanol as fuel isn't all that much better for the environment than using gasoline. One might think that burning the biofuel would release only the carbon dioxide that corn captures as it grows. But that simplified picture, which has often been conjured up to support the use of ethanol fuel, doesn't withstand closer scrutiny.

In fact, Polasky says, the fossil fuels needed to raise and harvest corn and produce ethanol are responsible for significant carbon emissions. Not only that, but the cultivation of corn also produces two other potent greenhouse gases: nitric oxide and methane. Polasky calculates that corn-derived ethanol is responsible for greenhouse-gas emissions about 15 to 20 percent below those associated with gasoline: "The bottom line is that you're getting a slight saving in terms of greenhouse-gas emissions, but not much."

If corn-derived ethanol has had little impact on energy markets and greenhouse-gas emissions, however, its production could have repercussions throughout the agricultural markets. Not only are corn prices up, but so are soybean prices, because farmers planted fewer soybeans to make room for corn.

In the May/June 2007 issue of *Foreign Affairs*, C. Ford Runge, a professor of applied economics and law at Minnesota, cowrote an article titled "How Biofuels Could Starve the Poor," which argued that "the enormous volume of corn required by the ethanol industry is sending shock waves through the food system." Six months later, sitting in a large office from which he directs the university's Center for International Food and Agricultural Policy, Runge seems bemused by the criticism that his article received from local politicians and those in the ethanol business. But he is steadfast in his argument: "It is clearly the case that milk prices, bread prices, are all rising at three times the average rate of increase of the last 10 years. It's appreciable, and it is beginning to be appreciated."

The recent OECD report, released in early September, is just the latest confirmation of his warnings, says Runge. And because a larger percentage of their income goes to food, he says, "this is really going to hit poor people." Since the United States exports about 20 percent of its corn, the poor in the rest of the world are at particular risk. Runge cites the doubling in the price of tortillas in Mexico a year ago.

All these factors argue against the promise of corn ethanol as a solution to the energy problem. "My take," says Polasky, "is that [ethanol] is only going to be a bit player in terms of energy supplies." He calculates that even if all the corn planted in the United States were used for ethanol, the biofuel would still displace only 12 percent of gasoline consumption. "If I'm doing this for energy policy, I don't see the payback," he says. "If we're doing this as farm support policy, there may be more merit there. But we're going to have to go to the next generation of technology to have a significant impact on the energy markets."

SUPERBUGS

Since the oil crisis of the 1970s, when the price of a barrel of petroleum peaked, chemical and biological engineers have chased after ways to turn the nation's vast reserves of "cellulosic" material such as wood, agricultural residues, and perennial grasses into ethanol and other biofuels. Last year, citing another of President Bush's goals—reducing U.S. gasoline consumption by 20 percent in 10 years—the U.S. Department of Energy (DOE) announced up to $385 million in funding for six "biorefinery" projects that will use various technologies to produce ethanol from biomass ranging from wood chips to switchgrass.

According to a 2005 report by the DOE and the U.S. Department of Agriculture, the country has enough available forest and agricultural land to produce 1.3 billion tons of biomass that could go toward biofuels. Beyond providing a vast supply of cheap feed-

GOLD PILE A coproduct of corn ethanol production is a valuable animal feed called distillers dried grains. The high-protein grains can be fed to dairy cows, cattle, pigs, and poultry.

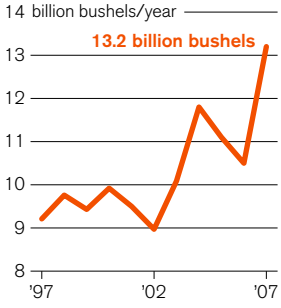
BOOM OR BUST?

Economics will determine the fate of biofuels.

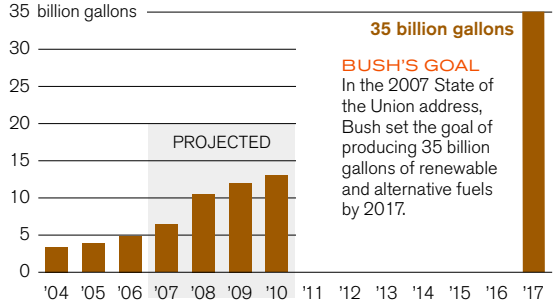
CORN GROWTH

The increase in the production of ethanol has prompted farmers to grow record amounts of corn. In 2006, about 17 percent of the U.S. corn crop went into production of the biofuel.

Corn production rises ...



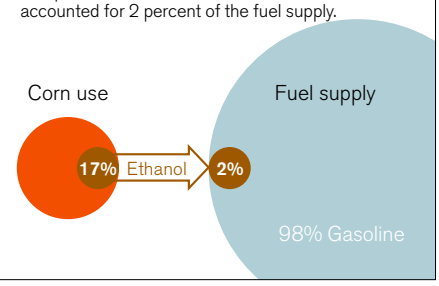
... as ethanol production increases to meet lofty goals ...



BUSH'S GOAL
In the 2007 State of the Union address, Bush set the goal of producing 35 billion gallons of renewable and alternative fuels by 2017.

... though the impact is small.

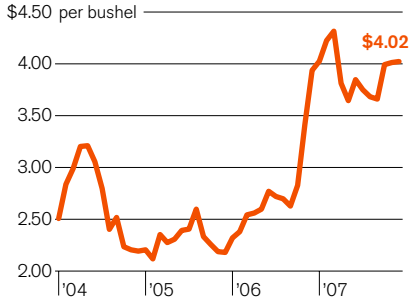
In 2006, 17 percent of the corn crop was processed into ethanol. That ethanol accounted for 2 percent of the fuel supply.



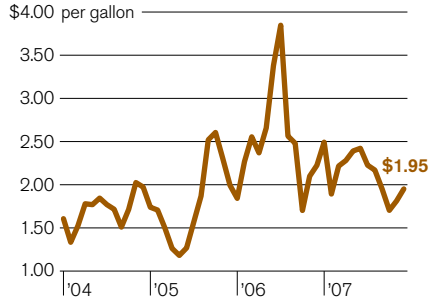
TIGHT MARGINS

The combination of rising corn prices and falling ethanol prices means producers of corn-derived biofuels are facing are facing tight margins and an uncertain economic future.

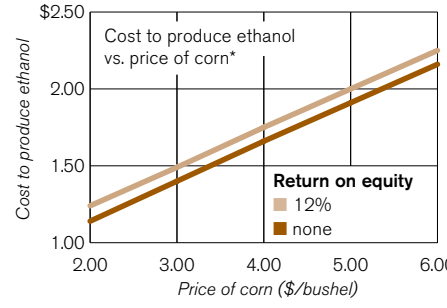
Corn prices are up ...



... but ethanol prices remain low ...



... making it difficult to produce profitably.



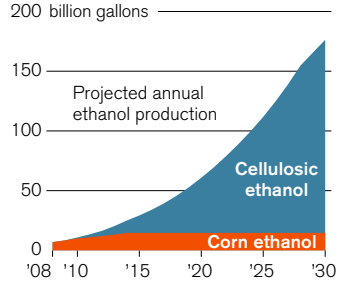
BIOFUEL FUTURE

Commercial production of biofuels from cellulosic biomass is at least four to five years away. But the technology has economic and environmental advantages over corn ethanol.

Commercial cellulosic facilities are being built ...

Company/Location	Technology used: *Thermochemical*	*Biochemical*
Abengoa Bioenergy/KS	●	●
Alico/FL	●	
BlueFire Ethanol/CA		●
Broin/IA		●
Iogen/ID		●
Range Fuels/GA	●	

... and may be the primary source ...



... of cleaner, more efficient ethanol.

Ethanol from:	Corn	Cellulose
Fossil energy used in production		
Energy produced	1.3 times	10 times
Greenhouse-gas reduction**	12% to 26%	82% to 85%

*Cost of producing 120 million gallons of ethanol in a newly constructed plant **Versus gasoline*

Sources from upper left to bottom right: USDA; Vernon Eidman; Stephan Polasky/Jason Hill; Bloomberg (as of 11/13); Bloomberg (as of 11/12); Eidman; DOE; Khosla Ventures; Eidman

CHARTS: THOMAS McCALL

stock, cellulosic biomass could greatly increase the energy and environmental benefits of biofuels. It takes far less energy to grow cellulosic materials than to grow corn, and portions of the biomass can be used to help power the production process. (The sugarcane-based ethanol produced in Brazil also offers improvements over corn-based ethanol, thanks to the crop's large yields and high sugar content.)

But despite years of research and recent investment in scaling up production processes, no commercial facility yet makes cellulosic ethanol. The economic explanation is simple: it costs far too much to build such a facility. Cellulose, a long-chain polysaccharide that makes up much of the mass of woody plants and crop residues such as cornstalks, is difficult—and thus expensive—to break down.

Several technologies for producing cellulosic ethanol do exist. The cellulose can be heated at high pressure in the presence of oxygen to form synthesis gas, a mixture of carbon monoxide and hydrogen that is readily turned into ethanol and other fuels. Alternatively, industrial enzymes can break the cellulose down into sugars. The sugars then feed fermentation reactors in which microörganisms produce ethanol. But all these processes are still far too expensive to use commercially.

Even advocates of cellulosic ethanol put the capital costs of constructing a manufacturing plant at more than twice those for a corn-based facility, and other estimates range from three times the cost to five. "You can make cellulosic ethanol today, but at a price that is far from perfect," says Christopher Somerville, a plant biologist at the University of California, Berkeley, who studies how cellulose is formed and used in the cell walls of plants.

"Cellulose has physical and chemical properties that make it difficult to access and difficult to break down," explains Caltech's Arnold, who has worked on and off on the biological approach to producing cellulosic ethanol since the 1970s. For one thing, cellulose fibers are held together by a substance called lignin, which is "a bit like asphalt," Arnold says. Once the lignin is removed, the cellulose can be broken down by enzymes, but they are expensive, and existing enzymes are not ideal for the task.

Many researchers believe that the most promising way to make cellulosic biofuels economically competitive involves the creation—or the discovery—of "superbugs," microörganisms that can break down cellulose to sugars and then ferment those sugars into ethanol. The idea is to take what is now a multistep process requiring the addition of costly enzymes and turn it into a simple, one-step process, referred to in the industry as consolidated bioprocessing. According to Lee Lynd, a professor of engineering at Dartmouth College and cofounder of Mascoma, a company based in Cambridge, MA, that is commercializing a version of the technology, the consolidated approach could eventually produce ethanol at 70 cents a gallon. "It would be a transformational breakthrough," he says. "There's no doubt it would be attractive."

But finding superbugs has proved difficult. For decades, scientists have known of bacteria that can degrade cellulose and also produce some ethanol. Yet none can do the job quickly and efficiently enough to be useful for large-scale manufacturing.

Nature, Arnold explains, offers little help. "There are some organisms that break down cellulose," she says, "but the problem is that they don't make fuels, so that doesn't do you much good." An alternative, she says, is to genetically modify *E. coli* and yeast so that they secrete enzymes that degrade cellulose. But while many different kinds of enzymes could do the job, "most them don't like to be inserted into *E. coli* and yeast."

Arnold, however, is optimistic that the right organism will be discovered. "You never know what will happen tomorrow," she says, "whether it's done using synthetic biology or someone just scrapes one off the bottom of their shoe."

She didn't quite scrape it off her shoe, but Susan Leschine, a microbiologist at the University of Massachusetts, Amherst, believes she just might have stumbled on a bug that will do the job. She found it in a soil sample collected more than a decade ago from the woods surrounding the Quabbin Reservoir, about 15 miles from her lab. The Quabbin sample was just one of many from around the world that Leschine was studying, so it was several years before she finished analyzing it. But when she did, she realized that one of its bacteria, *Clostridium phytofermentans*, had extraordinary properties. "It decomposes nearly all the components of the plant, and it forms ethanol as the main product," she says. "It produces prodigious amounts of ethanol."

Leschine founded a company in Amherst, SunEthanol, that will attempt to scale up ethanol production using the bacterium. There's "a long way to go," she acknowledges, but she adds that "what we have is very different, and that gives us a leg up. We already have a microbe and have demonstrated it on real feedstocks." Leschine says that other useful microbes are probably waiting to be discovered: a single soil sample, after all, contains hundred of thousands of varieties. "In this zoo of microbes," she says, "we can think that there are others with similar properties out there."

BLOOMING PRAIRIES

Whether ethanol made from cellulosic biomass is good or bad for the environment, however, depends on what kind of biomass it is and how it is grown.

In his office in St. Paul, David Tilman, a professor of ecology at the University of Minnesota, pulls out a large aerial photo of a field sectioned into a neat grid. Even from the camera's vantage point far above the ground, the land looks poor. In one plot are thin rows of grasses, the sandy soil visible beneath. Tilman says the land was so infertile that agricultural use of it had been abandoned. Then he and his colleagues scraped off any remaining topsoil. "No farmer has land this bad," he says.

In a series of tests, Tilman grew a mixture of native prairie grasses (including switchgrass) in some of the field's plots and single species in others. The results show that a diverse mix of grasses, even grown in extremely infertile soil, "could be a valuable source of biofuels," he says. "You could make more ethanol from an acre [of the mixed grasses] than you could from an acre of corn." Better yet, in a paper published in *Science*, Tilman showed that the prairie grasses could be used to make ethanol that is "carbon negative": the grasses might consume and store more carbon dioxide than is released by producing and burning the fuel made from them.

The findings are striking because they suggest an environmentally beneficial way to produce massive amounts of biofuels without competing with food crops. By 2050, according to Tilman, the world will need a billion hectares more land for food. "That's the land mass of the entire United States just to feed the world," he says. "If you did a lot of biofuels on [arable] land—it is very easy to envision a billion hectares for biofuels—you will have no nature left and no reserve of land after 50 years." Instead, Tilman argues, it makes sense to grow biomass for fuels on relatively infertile land no longer used for agriculture.

But down the hill from Tilman's office, his colleagues in the applied-economics department worry about the practical issues involved in using large amounts of biomass to make fuel. For one thing, they point out, the technology and infrastructure that could efficiently handle and transport the bulky biomass still need to be developed. And since the plant material will be expensive to move around, biofuel production facilities will have to be built close to the sources of feedstock—probably within 50 miles.

The amount of biomass needed to feed even one medium-size ethanol facility is daunting. Eidman calculates that a facility producing 50 million gallons per year would require a truck loaded with biomass to arrive every six minutes around the clock. What's more, he says, the feedstock is "not free": it will cost around $60 to $70 a ton, or about 75 cents per gallon of ethanol. "That's where a lot of people get fooled," he adds.

Since no commercial cellulosic facility has been built, says Eidman, it is difficult to analyze the specific costs of various technologies. Overall, he suggests, the economics look "interesting"—but cellulosic ethanol will have to compete with corn-derived biofuels and get down to something like $1.50 a gallon. Eidman believes it will be at least 2015 before biofuels made from cellulose "are much of a factor" in the market.

EXILED

While chemical engineers, microbiologists, agronomists, and others struggle to find ways of making cellulosic ethanol commercially competitive, a few synthetic biologists and metabolic engineers are focusing on an entirely different strategy. More than fifteen hundred miles away from the Midwest's corn belt, several California-based, venture-backed startups founded by pioneers in the fledging field of synthetic biology are creating new microörganisms designed to make biofuels other than ethanol.

Ethanol, after all, is hardly an ideal fuel. A two-carbon molecule, it has only two-thirds the energy content of gasoline, which is a mix of long-chain hydrocarbons. Put another way, it would take about a gallon and a half of ethanol to yield the same mileage as a gallon of gasoline. And because ethanol mixes with water, a costly distillation step is required at the end of the fermentation process. What's more, because ethanol is more easily contaminated with water than hydrocarbons are, it can't be shipped in the petroleum pipelines used to cheaply distribute gasoline throughout the United States. Ethanol must be shipped in specialized rail cars (trucks, with their relatively small payloads, are usually far too expensive), adding to the cost of the fuel.

So instead of ethanol, the California startups are planning to produce novel hydrocarbons. Like ethanol, the new compounds are fermented from sugars, but they are designed to more closely resemble gasoline, diesel, and even jet fuel. "We took a look at ethanol," says Neil Renninger, senior vice president of development and cofounder of Amyris Biotechnologies in Emeryville, CA, "and realized the limitations and the desire to make something that looked more like conventional fuels. Essentially, we wanted to make hydrocarbons. Hydrocarbons are what are currently in fuels, and hydrocarbons make the best fuels because we have designed our engines to work with them." If the researchers can genetically engineer microbes that produce such compounds, it will completely change the economics of biofuels.

The problem is that nature offers no known examples of microörganisms that can ferment sugars into the types of hydrocarbons useful for fuel. So synthetic biologists have to start from scratch. They identify promising metabolic reactions in other organisms and insert the corresponding genes into *E. coli* or yeast, recombining metabolic pathways until they yield the desired products.

At LS9 in San Carlos, CA, researchers are turning *E. coli* into a hydrocarbon producer by reëngineering its fatty-acid metabolism *(see "Better Biofuels," Forward, July/August 2007)*. Stephen del Cardayré, LS9's vice president of research and development, says the company decided to focus on fatty acids because organisms naturally produce them in abundance, as a way of storing energy. "We wanted to take advantage of a pathway that [naturally] makes a lot of stuff," del Cardayré says. "Just grab your middle." Del Cardayré and his coworkers use many of the existing pathways in *E. coli*'s fatty-acid metabolism but divert them near the end of the metabolic cycle. Since fatty acids consist of a hydrocarbon chain with a carboxyl group, it is relatively straightforward to make the hydrocarbon fuels. "Think of it as a highway," says del

Cardayré. "Near the end of the highway, we add a detour, a pathway we designed and stuck there, so the fatty acids have a better place to go. We pull them off and chemically change them, using this new synthetic pathway that takes them to products that we want."

Amyris, too, is taking the synthetic-biology approach, but instead of tweaking fatty-acid metabolism, it is working on pathways that produce isoprenoids, a large class of natural compounds. So far, however, both LS9 and Amyris are making their biofuels a few liters at a time. And while the companies have ambitious schedules for commercializing their technologies—both claim that their processes will be ready by 2010—improving the yield and the speed of their reactions remains a critical challenge. "It's where most of the biological work is going on," says Renninger. "We still have a little way to go, and that little way is very important."

If eventually commercialized, the hydrocarbon biofuels made by LS9 and Amyris could overcome many of the economic disadvantages of ethanol. Unlike ethanol, hydrocarbons separate from water during the production process, so no energy-intensive distillation step is necessary. And hydrocarbon biofuels could be shipped in existing petroleum pipelines. "It's all about cost," says Robert Walsh, president of LS9. But a critical factor will be the price of feedstock, he says. "We want dirt-cheap sugars."

> "Biomass is the only feedstock in sufficient quantities to cost-effectively replace oil," Vinod Khosla says. "Nothing else exists." Hybrid and electric vehicles, he adds, are "just toys."

Indeed, the synthetic-biology startups face the same problem that established ethanol producers do: corn is not an inexpensive source of biofuels. "The next generation [of feedstock] will be cellulosic," says John Melo, CEO of Amyris. "But we are not sure which cellulosic technology will emerge as the winner." Whichever technology prevails, Melo says, Amyris expects to be able to "bolt it" onto its fermentation process, giving the company the advantages of both cheap cellulosic feedstocks and practical hydrocarbon fuels.

For now, though, the lack of an alternative to corn is driving Amyris right out of the country. The company, which plans to retrofit existing ethanol plants so that they can make hydrocarbons, will initially work with Brazilian biofuel facilities that are using sugarcane as a feedstock. Given the price of corn and the amount of energy needed to produce it, Melo says, Brazilian cane offers the most "viable, sustainable" way to make biofuels today.

NO CHOICE

Even in a Silicon Valley culture that reveres successful venture capitalists, Vinod Khosla has a special place of honor. A cofounder of Sun Microsystems in the early 1980s, Khosla later joined the venture capital firm Kleiner Perkins Caufield and Byers, where in the late 1990s and early 2000s he gained a reputation for ignoring the dot-com excitement in favor of a series of esoteric startups in the far less glamorous field of optical networking. When several of the startups sold for billions of dollars to large companies gearing up their infrastructure for the Internet boom, Khosla became, in the words of one overheated headline of the time, "The No. 1 VC on the Planet."

These days Khosla, who is now among the world's richest people (the Forbes 400 lists him at 317, with a net worth of $1.5 billion), is putting most of his investments in alternative energies. He counts among his portfolio companies more than a dozen biofuel startups—synthetic-biology companies LS9 and Amyris, cellulosic companies like Mascoma, and corn ethanol companies like Cilion, based in Goshen, CA. But to call Khosla simply an investor in biofuels would greatly understate his involvement. In the last several years, he has emerged as one of the world's leading advocates of the technology, promoting its virtues and freely debating any detractors *(see Q&A, March/April 2007)*.

Khosla seems exasperated by the biofuels naysayers. Climate change, he says, is "by far the biggest issue" driving his interest in biofuels. If we want to head off climate change and decrease consumption of gasoline, "there are no alternatives" to using cellulosic biofuels for transportation. "Biomass is the only feedstock in sufficient quantities to cost-effectively replace oil," he says. "Nothing else exists." Hybrid and electric vehicles, he adds, are "just toys."

In particular, argues Khosla, any transportation technology needs to compete in China and India, the fastest-growing automotive markets in the world. "It's no big deal to sell a million plug-in electrics in a place like California," he says. The difficulty is selling a $20,000 hybrid vehicle in India. "No friggin' chance. And any technology not adoptable by China and India is irrelevant to climate change," he says. "Environmentalists don't focus on scalability. If you can't scale it up, it is just a toy. Hence the need for biofuels. Hence biofuels from biomass."

In a number of opinion papers posted on the website of Khosla Ventures, a firm he started in 2004 that has invested heavily in biofuels and other environmental technologies, Khosla envisions biofuel production rapidly increasing over the next 20 years. According to his numbers, production of corn ethanol will level off at 15 billion gallons a year by 2014, but cellulosic ethanol will increase steadily, reaching 140 billion gallons by 2030. At that point,

he predicts, biofuels will be cheap and abundant enough to replace gasoline for almost all purposes.

While Khosla readily acknowledges the limitations of corn-derived ethanol, he says it has been an important "stepping-stone": the market for corn ethanol has created an infrastructure and market for biofuels in general, removing many of the business risks of investing in cellulosic ethanol. "The reason that I like [corn ethanol] is that its trajectory leads to cellulosic ethanol," he says. "Without corn ethanol, no one would be investing in cellulosics."

But back in the Midwest, there is a "show me" attitude toward such blue-sky projections, and there are lingering questions about just how the nation's vast agricultural infrastructure will switch over to biomass. If Khosla's projections prove out, "then wonderful," says the University of Minnesota's Runge. "Meanwhile, we're stuck in reality." Perhaps the main point of contention, Runge suggests, is whether corn ethanol will in fact lead to new technologies—or stand in their way. "It is my opinion that corn ethanol is a barrier to converting to cellulosics," he says, pointing to the inertia caused by political and business interests heavily invested in corn ethanol and its infrastructure.

Runge is not alone in his skepticism. "Unless the cost is reduced significantly, cellulosic ethanol is going nowhere," says Wally Tyner, a professor of agricultural economics at Purdue University. Making cellulosic ethanol viable will require either a "policy mechanism" to encourage investment in new technologies or a "phenomenal breakthrough"—and "the likelihood of that is not too high," Tyner says. Farmers and ethanol producers currently have no incentive to take on the risks of changing technologies, he adds. There is "no policy bridge" to help make the transition. "The status quo won't do it."

Despite the sharp differences of opinion, there's still some common ground between people like Khosla, whose unbridled faith in innovation has been nurtured by the successes of Silicon Valley, and the Midwesterners whose pragmatism was forged by the competitive economics of agriculture. In particular, most observers agree that annual production of corn-derived ethanol will level off within a few years. After that, any growth in biofuel production will need to come from new technologies.

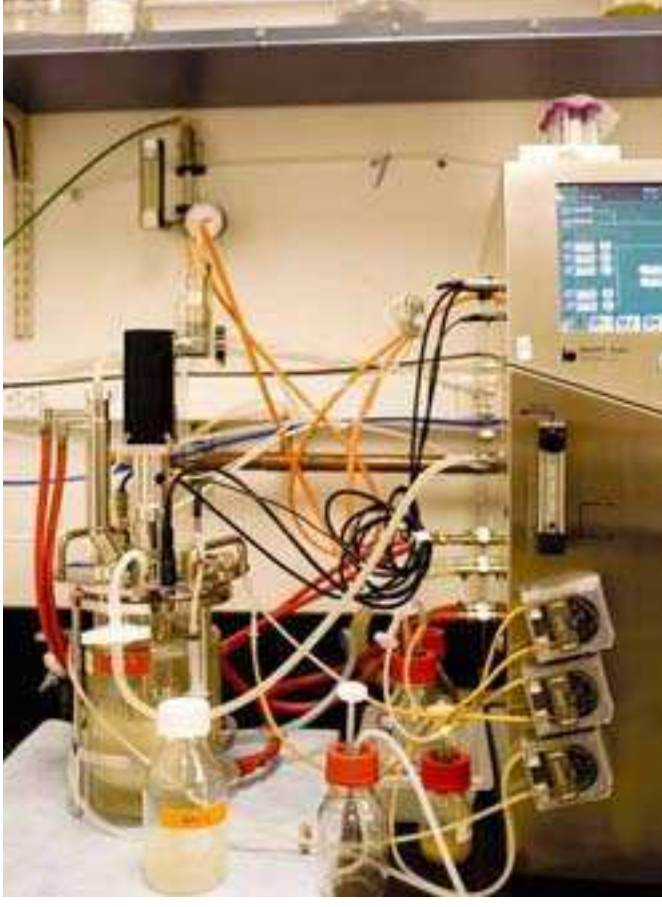
But if cellulosic biofuels are to begin replacing gasoline within five to ten years, facilities will need to start construction soon. This fall, Range Fuels, a company based in Broomfield, CO, announced that it had begun work in Georgia on what it claims is the country's first commercial-scale cellulosic-ethanol plant. The Range facility, which will use thermochemical technology to make ethanol from wood chips, is scheduled to reach a capacity of 20 million gallons in 2008 and eventually increase to 100 million gallons a year. Meanwhile, Mascoma has announced several demonstration units, including a facility in Tennessee that will be the first cellulosic-ethanol plant built to use switchgrass. But these production plants are federally subsidized or are a result of partnerships with state development organizations; attracting private investment for commercial-scale production will be another matter.

Indeed, ramping up the capacity of cellulosic-ethanol production will be a huge and risky challenge, says Colin South, president of Mascoma. "When people talk about cellulosic ethanol as if it is an industry, it is an unfair portrayal," he says. "There are a number of pilot plants, but none of them have gotten out of the pilot scale. We still need to show we can actually run these in the form of an operating chemical plant." South says that Mascoma hopes to begin construction of a commercial plant in 2009 and have it up and running by early 2011. But he adds that the company will only proceed when "the numbers are good enough."

Perhaps the most crucial number, however, will be the price of crude oil. If it stays high, cellulosic-ethanol production could become economically competitive much sooner. But few people, least of all the investors who would risk hundred of millions of dollars on new plants, are willing to take that bet. Many remem-

CREATING NEW FUELS Amyris Biotechnologies is scaling up production of hydrocarbons made using genetically engineered *E. coli*. In a 100-liter fermentation unit, the microbes convert sugars into the hydrocarbon fuels (right center); additional experimentation to improve the process is done in a two-liter bioreactor (far right). Lab bottles (above) are ready to be attached to the bioreactors to "feed" the fermentation process. A micrograph (bottom right) shows the *E. coli* cells as small, dark rods surrounded by the large amounts of pure hydrocarbon diesel produced by the bacteria.

www For further exploration of (and debate about) biofuels: **technologyreview.com/biofuels**



PHOTOS: JEN SISKA; MICROGRAPH COURTESY OF AMYRIS

ber the late 1970s, when the federal government earmarked roughly a billion dollars to fund biomass-related research, only to abandon it when crude-oil prices fell in the early 1980s. And while the price of a barrel of crude hovered in the mid-$90s this fall, and wholesale gas prices reached $2.50 a gallon, biofuel experts say they cannot count on such high prices. Many producers of next-generation biofuels say they want to be competitive with crude oil at around $45 a barrel to ensure long-term viability in the market.

Indeed, announcements about new cellulosic-ethanol plants tend to obscure the fact that the technology is still not economically viable. Gregory Stephanopoulos, a professor of chemical engineering at MIT, describes himself as "very optimistic" about the future of biofuels. But even he is quick to add that it will take another 10 years to optimize production processes for cellulosic biofuels. Among myriad other problems, he says, is the need for more robust and versatile microbes to make them.

In a small conference room outside his office, Stephanopoulos takes out a pencil and paper and begins to draw a series of circles. You can imagine, he says, a biorefinery surrounded by sources of different types of biomass. He connects the circles at a central point, making lines like spokes on a wheel. You could, he goes on, imagine pipelines from these sources. What if the biomass were treated and piped to the biorefinery as a slurry? Stephanopoulos would be the first to acknowledge that such an ambitious infrastructure would take years to put in place, and that the idea raises numerous technical and engineering questions. But for the rest of the interview, the drawing sits patiently on the table—a simple target. TR

DAVID ROTMAN IS *TECHNOLOGY REVIEW*'S EDITOR.

By JON COHEN

The Genetics of Language

RESEARCHERS ARE BEGINNING TO CRACK THE GENETIC CODE THAT GIVES HUMANS OUR UNIQUE WAY WITH WORDS.

Daniel Geschwind reaches up to his office bookshelf, takes down a three-dimensional puzzle of the human brain, and begins trying to snap the plastic pieces together. A neurogeneticist at the University of California, Los Angeles, Geschwind hopes the puzzle will help him describe the parts of the brain that control speech and language. But for the life of him, he can't figure out how the left and right hemispheres attach. "I'm really bad spatially, so don't make fun of me," he pleads. "It's like I'm having a little stroke or something. I'll get it together, and then I'll figure it out."

The plastic model may have momentarily flummoxed Geschwind, but when it comes to the genes that govern the brain's development and functions, he excels at putting the pieces together. Over the past few years, he has emerged as one of the leading geneticists in a nascent field that aims to spell out which genes are related to speech and language development—and how our intelligence and communication skills evolved beyond those of our ape relatives, giving us the unique ability to speak.

Research like Geschwind's sits at the intersection of two fields: behavioral genetics and evolutionary biology. Each field depends on the other to make sense of the flood of studies on the genetics of language now pouring out of labs around the world. To peer into the human brain and see how it typically stores, uses, and comprehends words, Geschwind investigates not only normal human brains but also those where the process goes awry, studying the genes of families afflicted by autism, dyslexia, schizophrenia, and other conditions that can involve speech and language disorders. This research may help make diagnosis and treatment of language-related disorders more precise, but it also has a more basic purpose. "Studying disease is really a fundamental way to understand normal function," says Geschwind. "Disease has given us extraordinary insight to understand how the brain works or might not work."

While behavioral genetics compares the genes of people with different abilities, evolutionary biology compares the genes of different species. Researchers use this data to determine what limits other species' communication skills and what expanded ours so dramatically that language became one of our defining characteristics. Geschwind's own forays into evolutionary biology have led him to look at DNA in the brains of chimpanzees, monkeys, and even songbirds. "A lot of people think our lab is all over the place," he says. "It's actually pretty integrated. Language is complex, and the only way we're going to have a hit is when two or three findings point to the same place."

With the help of improved techniques for detecting DNA, as well as cutting-edge analytical tools and the genome sequences of species from humans to mice, Geschwind and other researchers have begun to tease out how we evolved the capacity for sophisticated speech. But though neuroscientists working in the postgenomic era have made a lot of progress, they have only begun to scratch the surface of how the relevant genes are collectively put into action.

FOXP2 HUNTING

Despite more than a decade of effort and many tantalizing leads, neurogeneticists have so far definitively linked only a single gene to speech and language. The story of its discovery begins in 1990, when clinical geneticists at the Institute of Child Health in London first reported a speech disorder that appeared in three generations of Britons known as the KE family. The doctors took note of 15 affected members who seemed to have inherited problems with grammar, syntax, and vocabulary that were tied to poor control of facial muscles and difficulty pronouncing words. Although it seemed clear that

Illustration by RONALD KURNIAWAN


talk
Hello
Привет

there had to be a genetic link, researchers hunted for more than a decade before they found the gene responsible.

The big break came in 1998, when University of Oxford geneticists led by Anthony Monaco and Simon Fisher identified a distinct chunk of chromosome 7 linked to the speech and language problems found in the KE family. Yet the region held dozens of genes, and they couldn't pinpoint the one bad actor. Enter Jane Hurst, a clinical geneticist who worked at a hospital on Oxford's grounds and, coincidentally, had coauthored the first report on the KE family.

The chromosome 7 paper led Hurst to reëxamine the results of an amniocentesis, for a pregnant woman unrelated to the KE family, that she had reviewed four years earlier. Hurst had found that the fetus had a chromosomal hiccup called a translocation, and she later learned that the child developed speech and language problems strikingly similar to those seen in the KE family. Looking at the results again, she saw that the translocation had occurred in the very same region of chromosome 7 that Fisher had identified. "I phoned up Simon and said, 'I found you the patient who's going to get you the gene,'" recalls Hurst, adding that she wasn't serious. But that's precisely what happened: the translocation in the boy disrupted a gene called *FOXP2*, which it turned out had been mutated in the 15 members of the KE family who exhibited severe problems.

When Monaco, Fisher, Hurst, and coworkers reported the convergent *FOXP2* findings in the October 4, 2001, issue of *Nature*, it made international headlines—and, more important, announced the start of a new era in speech and language research.

Even then, the scientists knew that *FOXP2* does not singlehandedly wire the brain for language. In the grand theater of the genome, it is cast as a transcription factor, turning other genes on or off by telling them whether to transcribe their DNA into messenger RNA, which leads to the production of proteins. And *FOXP2* has a broad repertoire in embryonic development, playing critical roles in the formation of the lungs, heart, and intestines.

Yet *FOXP2* is clearly involved, too, in the molecular pathways behind speech and language. Clinicians in several countries have now reported patients with aberrant *FOXP2* genes and KE-like speech and language problems. Geschwind has taken some of the first steps in uncovering the connection between *FOXP2* and language. He and Fisher recently studied human fetal brains and neural-cell cultures to identify which genes the FOXP2 protein turns on or off in the brain. They connected FOXP2 to more than 200 genes that control the development of neurons, the release of neurotransmitters that send messages between nerves, and the changes in synapses that underlie learning and memory. Some of these genes will very likely turn out to be involved in speech and language. To sift this genetic river for the gems, Geschwind is zooming in on about 15 genes that also have ties to schizophrenia, as well as 34 genes to which FOXP2 binds in two areas of the brain that other studies have shown are involved with language and speech.

To date, the discovery of *FOXP2*'s link to speech and language has yielded more questions than answers. But it has kicked open a door that neuroscientists had been knocking on for over a century.

THE KNOTTY MIND

In 1861, Pierre Paul Broca came to a meeting of the Anthropological Society of Paris with another man's brain. Broca, a surgeon and neurologist who was the society's founder, had retrieved the brain from an unusual patient who had been hospitalized for 30 years. The patient was known as Tan because he would answer "Tan, tan" to any question put to him. He eventually lost the ability to speak altogether, although he understood almost everything he heard. Broca first met Tan only five days before his death, when he arrived in the surgery unit because of a massive, gangrenous infection. On autopsy, Broca found that Tan's brain contained a number of lesions, the most extensive and oldest of which was in the middle of the left frontal lobe. Broca asserted that this damage caused Tan's loss of speech.

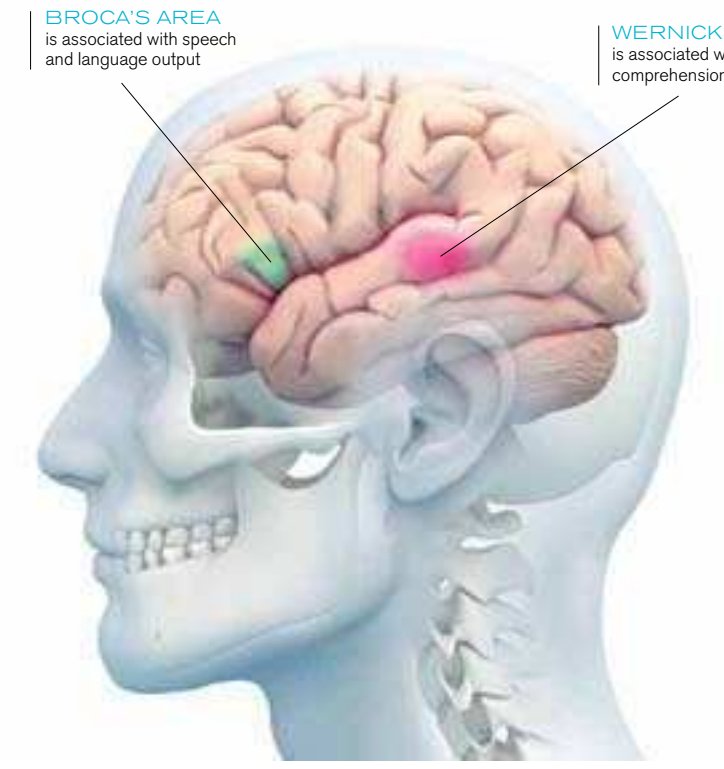
Thirteen years later, the German physician Carl Wernicke described the brain of a stroke patient who could speak but had immense difficulty understanding what was said to him. Again, a lesion in the left hemisphere stood out, although it was farther back, near the intersection of the temporal and parietal lobes.

As Geschwind explains the importance of what are now known as Broca's and Wernicke's areas, he points out the cerebral real estate they occupy on the plastic brain he has finally assembled. Subsequent research has shown that both areas do play critical roles in speech and language. Though damage to either does not always cause problems, the neural circuitry for speech typically runs along the left Sylvian fissure—a sort of neural Grand Canyon that stretches from Broca's area to Wernicke's.

Geschwind has been captivated by this asymmetry, and by its relationship to handedness. Roughly 90 percent of us are right-handed, and nearly all righties depend on that left "perisylvian" region for speech and language. (About 40 percent of lefties instead rely on the right perisylvian region or use both hemispheres.) "There's some kind of benefit to the kind of processing that's going on in language—which is extremely rapid processing—to keep everything in one circuit in one hemisphere," he concludes.

The process that creates asymmetry often goes amiss in people with dyslexia, schizophrenia, or autism—all disorders with links to language problems. So Geschwind and others have set about hunting for genetic aberrations implicated in language disorders and for genes linked to differences in brain asymmetry, such as those related to handedness.

While the discovery of the mutation in *FOXP2* required great effort (and a dollop of luck), all told it involved analyzing the DNA of no more than 50 people. In contrast, no simple mutation of a single gene is likely to disrupt brain asymmetry or cause dyslexia,



JOHN MACNEILL

LOCATING LANGUAGE

The neural circuitry for speech and language is typically localized in the left hemisphere of the brain, along a region called the Sylvian fissure that stretches from Broca's area to Wernicke's. Researchers are searching for the genes that wire these regions and produce the uniquely human capacity for speech.

schizophrenia, or autism. Rather, these problems are caused by subtle aberrations in genes and networks of genes working in concert. That subtlety forces researchers to collect and sort through DNA from hundreds if not thousands of people. For example, the Autism Genome Project, a large international collaboration in which Geschwind participates, performed an analysis of more than 1,400 families that have at least two members affected by autism-spectrum disorders. This massive study didn't isolate a single mutant gene, but it did find intriguing links between the disorders and missing or extra copies of a region of chromosome 11. Such variations can increase or decrease the amount of protein produced by genes, with unpredictable effects.

Geschwind also contributed to a study, led by Oxford's Clyde Francks, that revealed some of the intricate connections among language-related disorders, brain asymmetry, and handedness. The study began as a hunt for a gene that controls handedness in dyslexics. Previous reports had suggested that dyslexics are more likely to be left-handed and that left-handed people are more likely to have reduced asymmetry. Francks and his colleagues could not corroborate that suggestion, but they did find a region of chromosome 2 that seemed linked to left-handedness. They then examined the DNA of pairs of healthy left-handed brothers: the same linkage to chromosome 2 surfaced, evidence that a gene or genes in that region might influence handedness. Adding still more bizarre connections, the team performed a study of siblings with schizophrenia, which implicated the same region.

To find the gene or genes at the heart of this knot of links, the researchers compared the same region of chromosome 2 in healthy right-handed people, healthy left-handed people, and people with schizophrenia. They found four DNA differences that distinguished the schizophrenics from the mentally healthy lefties; the location of these variations led them to a gene called *LRRTM1*. Geschwind collaborated in the work that helped identify where in the human brain *LRRTM1* was turned on, or expressed: it probably helps shape forebrain structures and influences how neurons connect. He suspects that in early gestation, it also contributes to brain asymmetry.

Francks and his colleagues think that certain variants of *LRRTM1* somehow decrease production of the LRRTM1 protein during fetal brain development. Presumably, reduced levels of LRRTM1 could have contributed to reduced brain asymmetry, tilting the developmental scales toward left-handedness and schizophrenia—and potentially toward a variety of speech and language problems.

All this adds up to little more than a list of genes that may or may not be involved in creating speech and language: *FOXP2*; genes that *FOXP2* interacts with; genes with copy number anomalies implicated in autism; and an aberrant gene connected to schizophrenia and left-handedness. Moving from correlations between genes and disorders to knowledge of the neural circuitry that allows a human but not a chimp to ask, "To be, or not to be?" requires researchers to find connections between seemingly disparate findings. To that end, Geschwind and others are turning to evolutionary studies that analyze these genes in other species and compare them with the human versions. Such studies may also provide clues to how humans evolved the capacity for language.

THE ORIGIN OF SPEECH

Like songbirds, dolphins, whales, bats, elephants, and—of course—humans, monkeys and apes can learn sounds and use them to communicate. For many decades, researchers have attempted to decode such animal messages. They have also tried to teach chimpanzees, bonobos, gorillas, and orangutans to use symbols, lexigrams, and sign language, and a few poster apes like Koko, Washoe, and Kanzi have no small measure of fame thanks to PBS documentaries, magazine cover stories, and books about their communication skills. Some have even shown what appears to be a remarkable ability to understand spoken words.

Nevertheless, an impassable border separates our speech and language abilities from theirs. The best-trained apes can learn

only a few hundred words. Most any human three-year-old has a larger vocabulary, and the average high-school graduate has a mental lexicon of about 60,000 words. Linguists and psychologists who have studied "talking apes," including researchers who have taught them to communicate, stress that the animals rarely combine even two words into a semantic whole and never utter the type of complex "recursive" sentence—like this one—that embeds one thought in another.

In the hope of beginning to explain this discrepancy, Geschwind investigated which genes are turned on in the brains of humans and in those of chimpanzees, our closest genetic relatives. He found hundreds of differences but had no way to determine which ones mattered—which were most significant in driving evolution and determining brain function. Overwhelmed, he turned to a mathematician friend at UCLA, Steve Horvath.

With Horvath's guidance, Geschwind and his grad student Michael Oldham arrived at a new way to approach the problem. Rather than looking at differences between individual genes, they analyzed differences between networks of genes expressed at the same time. Specifically, they looked at autopsied slices of human and chimp brains and compared these "coexpressed" genes in specific "modules," including the cerebral cortex, the cerebellum, and the primary visual cortex.

They found that within each module's networks, some genes served as hubs, connecting to many other genes. Diagrams of the networks look much like maps of airline routes, and both the human and chimp maps have a ridiculous number of hubs and spokes. But the diagrams make it easy to see the most important genes—those at the hubs. And when the team took the human map of a module and removed all the chimp connections for the same module, only a few genes were left. It became startlingly clear not only which genes are uniquely human, but also which of those are most important.

This approach yielded insights that weren't possible with older techniques; simply comparing human and chimp expression of individual genes misses the vast majority of variation that takes place between groups of genes. Though no new connections between genes and language have emerged yet, Geschwind and his colleagues did find that most of the differences occurred in the cerebral cortex—the very part of the brain that expanded the most in humans, and in which Broca's and Wernicke's areas reside. Geschwind is hopeful that taking a broader view of not only the genome but also the transcriptome—the set of genes that are turned on at any given time—will lead to more insights into the genetics of language. "We need to understand the transcriptome in the same way we understand the genome," he says.

So far, however, the most intriguing and concrete genetic clues to the evolution of speech and language have emerged from simple, direct comparisons of animal and human versions of *FOXP2*. "*FOXP2* is paradigmatic," says Geschwind. "It's this beacon, and the first proof that this area of research might lead to great insights about human beings and evolution."

Soon after Fisher, Monaco, and their colleagues linked *FOXP2* to human speech and language, they teamed up with a leading evolutionary-biology group headed by Svante Pääbo at the Max Planck Institute in Leipzig, Germany. They found that the protein made by the *FOXP2* gene in chimps is virtually identical to that made in mice: just one amino acid differs between the two. Biologists believe that if proteins undergo little alteration over an evolutionary span of tens of millions of years, they must perform such essential functions that they simply cannot tolerate change. But two amino acids in human FOXP2 differ from those in the chimp protein—a total of three changes from the mouse version. That the gene withstood such dramatic change in such a short time span (evolutionarily speaking) suggests that the change helped us survive—as the development of language surely did.

Then, in October 2007, Pääbo and coworkers published a jaw-dropping paper about *FOXP2* in Neanderthals, evolutionary relatives of modern humans that died out 30,000 years ago. The researchers isolated parts of the *FOXP2* gene from the bones of two Neanderthals. Although they have yet to sequence the entire gene, they found that Neanderthals and modern humans matched at the two critical spots that separate humans and chimpanzees. Though often depicted as knuckleheads, our closest hominid relatives may have shared at least some of our capacity for speech and language. "There is no reason to think that Neanderthals did not have language as we do," says Pääbo. But he adds that the many unknown genes involved in language will eventually have to be found and looked at in Neanderthals.

Geschwind is continuing his hunt for those unknown genes, applying to his behavioral-genetics work the technique he developed to compare human and chimp gene expression. His lab is now doing the same sort of coexpression studies on brains from healthy humans and schizophrenics, which he hopes will uncover connections that are broken in schizophrenia and perhaps lead to still more genetic pathways related to speech and language. He hopes eventually to do similar analyses with autopsied brains from people who had autism-spectrum disorders.

So far, Geschwind and his colleagues have found what amount to some interesting genetic words that they've been able to string into a few sentences to explain the roots of speech and language. They can't yet tell a coherent story. Still, confidence is building that in the not-too-distant future, scientists will be able to write a lengthy book about how we evolved our phenomenal gift of gab, highlighting the critical suites of genes that make it possible. If they do, they could also find ways to correct disruptions to this network—disruptions that can leave people at a serious loss for words. TR

JON COHEN, A SAN DIEGO–BASED FREELANCE WRITER, IS WORKING ON A BOOK THAT REËXAMINES THE DIFFERENCES BETWEEN HUMANS AND CHIMPANZEES.

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The Fleecing of the Avatars

MILLIONS OF REAL DOLLARS ARE CHANGING HANDS WITHIN VIRTUAL WORLDS. RECENT FRAUD ALLEGATIONS—SO FAR UNADDRESSED BY LAW ENFORCEMENT—ARE OMINOUS FOR THOSE WHO SEE SUCH ENVIRONMENTS AS FUTURE CENTERS OF E-COMMERCE.

By DAVID TALBOT

Stephanie Roberts is a 33-year-old parks service employee in a Chicago suburb where she lives with her brother and mother; in the winter, she drives the Zamboni at a public skating rink. But she's also Zania Turner, of glowing skin and impossibly luxuriant black hair, who sashays in silk dresses through the booming virtual world of Second Life, which is run by the San Francisco company Linden Lab. In her life as a 3-D cartoon, Roberts gathers with other avatars to role-play reënactments of obscure *Star Trek* cartoon episodes, build and buy digital homes and furniture, and hang out on digital beaches.

But Second Life is more than a game or a social-networking site; it's also a venue for financial transactions. The currency used within the virtual world, called Linden dollars, can be converted to U.S. dollars at a rate of roughly 270 to 1. More than $13 million worth of Lindens are in circulation, and 318,742 residents of Second Life—including Roberts—participate in its internal economy. "It's a fascinating and exciting place, because people are doing business in the absence of a lot of legal and regulatory structures," says Robert Bloomfield, a Cornell University accounting professor who studies virtual economies—and coined the term "metanomics" to describe the field.

But life on the lawless frontier means risks as well as opportunities, as Stephanie Roberts found out last summer. And what happened to her is a bit ominous for those who expect to see 3-D immersive environments become centers for e-commerce.

Trouble started at the Ice Dragon's Playpen, a recreational island in Second Life. With her movie-star looks—Roberts chose an avatar modeled after Catherine Zeta-Jones—Zania Turner had no trouble landing a job hosting a game of Slingo, which is something like bingo. She made 100 Lindens (37 cents) an hour, plus tips. And while steering Zania through various Second Life venues —such as the Moonshine Casino, where residents gambled, and FurNation, where they frolicked in the guise of animals (she was a white tiger at one stage)—Roberts saw places to deposit her money. "There were these machines. They said 'Bank,'" she says. The machines handed out notes to passing avatars, promoting account signups at something called Ginko Financial, which advertised high interest rates. "With Second Life, you need money to get land and stuff that other people build," she says. "So I thought, 'I might as well put something in there, especially with the good interest rate, and pull it out when I need to, and help get me some stuff in-world.'" A few mouse clicks later, she was an account holder. She enjoyed watching her money grow. Eventually she had amassed 39,000 Lindens, worth $144.

Ginko—operated by an avatar called Nicholas Portocarrero, whose real identity is not clear—persuaded hundreds of people to deposit their Linden dollars. The reasons for what happened next are murky, but the results were clear enough: the "bank" vanished, and depositors say their money did, too. In July 2007, residents began clustering around machines to try to recover their money after Ginko began restricting withdrawal amounts. Then Ginko announced that deposits were now in "Ginko perpetual bonds" rather than Linden dollars. Those bonds soon plunged in value, and in October, they ceased to exist. The reported losses may have totaled $700,000, according to Ben Duranske, a lawyer based in Idaho who writes a blog on virtual legal issues.

Some Second Lifers have reported losing thousands of dollars in Ginko. Roberts is among the luckier ones: she says she lost only her $144 in savings. But the point isn't just that somebody other

Photograph by HAYLEY MURPHY

VIRTUAL VICTIM
Stephanie Roberts, a Chicago-area woman and Second Life resident, has no way to recover real money that vanished in an in-world "bank."

than Roberts ended up with her money. What may be most significant is that nothing happened to whoever may have taken it. Her money disappeared into the 3-D ether.

That is not what we have come to expect from e-commerce. A combination of technical controls, laws, and regulation makes today's online business fairly safe (or at least as safe as business in the rest of the world), with wrongdoers subject to punishment. "A lot of the legislation over the last 10 years relating to online commercial [transactions] has all been about governments trying to create a level playing field where trust between buyers and sellers is created," says David Naylor, a partner in the U.K. law firm of Field Fisher Waterhouse, which in April became the first major law firm to establish a presence inside Second Life. As a result, people are now willing to make bank deposits online and enter their credit card numbers to make purchases. "An environment where it is easy and simple to defraud others, with them not having much of a comeback, if any, is not one which is going to lend itself well to significant business development," he says. "It's not the only factor, but it is a significant factor in the commercial attractiveness and viability of these environments. If you destroy the trust between a buyer and a seller—which is a fairly tenuous thing to establish in the online environment in the first place, where people lack face-to-face communication—you can quickly and massively impact people's willingness to transact with each other."

Although it created and issued the Second Life currency, Linden Lab denies responsibility for transactions, disputes, and losses involving Linden dollars. "People have got to deal with interactions [in virtual worlds] the same way they would deal with them on the Internet generally," says Ginsu Yoon, Linden's vice president for business affairs. "Understand what you are doing, understand what the consequences are, use available tools to make sure you are dealing with a trusted party." The company has now taken steps to identify and suspend accounts where large Linden transfers and cash-outs are taking place—activity that could point to fraud. It's also advising account holders to engage the services of third parties who provide identify verification. But whether such measures can make virtual economies functional in the absence of real-world prosecution or regulation remains to be seen.

VIRTUAL UPSTART
Roberts's avatar, Zania Turner, earned money hosting Slingo, a blend of bingo and slots. Roberts now dreams of selling virtual Zamboni machines.

COURTESY OF STEPHANIE ROBERTS

PARTY LIKE IT'S 1994

Second Life reports more than 10 million subscribers, including inactive or duplicate accounts; about 50,000 are online at any one time. But it is only one booming virtual world among many, including Entropia Universe and There; massively multiplayer online role-playing games like World of Warcraft; and more controlled and narrowly focused sites like the child-oriented Webkinz and Club Penguin, which is owned by Disney. Many corporations have their own virtual worlds—places where they assemble far-flung employees or students to collaborate on projects or attend classes. "Second Life gets a lot of press, but there are hundreds and hundreds of these platforms," says Sandy Kearney, global director of 3-D Internet and virtual business at IBM. "If you look at all the platforms coming, it feels like 1994, when all of a sudden everybody was building a website."

In just the past year, reports the trade organization Virtual Worlds Management, companies and venture capitalists have pumped a billion dollars into developing virtual worlds. Many mainstream businesses have presences—simulations, or "sims"—within them. Dell has a sales office in Second Life. Reebok has a store. The studio 20th Century Fox even held a movie premiere there, for *X-Men 3: The Last Stand*. IBM maintains business centers. In 2006, Sun Microsystems became the first Fortune 500 company to hold a press conference "in-world." Even the World Bank presented a report in Second Life about business development (20 percent of Second Lifers log on from Latin America, Asia, or Africa). Corporations have taken up residence in other virtual worlds, too; for example, you'll find Toyota's Scion brand in There.

With all this blue-chip interest, and continuing increases in processing horsepower and Internet bandwidth, virtual worlds may provide a peek at the future of the Web: instead of jumping from page to page, we could one day navigate 3-D environments to communicate, shop, and do research. Some observers even think that virtual worlds may merge with 3-D representations of the real world, such as Google Earth and Microsoft Live Search Maps *(see "Second Earth," July/August 2007)*. Many virtual worlds have their own currencies: in addition to Linden dollars, there are

The point isn't just that somebody else ended up with Roberts's money. It's that nothing happened to whoever may have taken it. Between her and other victims, as much as $700,000 disappeared into the 3-D ether. That is not what we have come to expect from e-commerce.

Project Entropia dollars, or PEDs (10 to the dollar), in the competing Entropia Universe; Therebucks (1,800 to the dollar) in the teen-focused There; and Webkinz KinzCash that kids use to buy treats for digital Chihuahuas and raccoons.

But big companies like Sun, Reebok, and IBM don't really do business in virtual worlds; they "tunnel" into them. To close a deal, you need to step out of the "sim" and into the traditional Sun or Reebok or IBM website. These companies deal only in real currency, using established protocols for encryption and authentication. By contrast, people like Stephanie Roberts are actively conducting transactions in virtual worlds, using virtual money to buy virtual clothing, land, animals, surfboards, and art for their avatars. They deposit money in virtual banks and even invest in virtual stocks. And that's where the problems are arising. The blogosphere is full of complaints about Ginko losses and about deals for land and goods that went wrong. And some fear that these issues will thwart the growth of e-commerce in virtual worlds.

To IBM's Kearney, the situation recalls the formative days of e-commerce, which were plagued by uncertainty and lack of trust. "If you look at early [Web] days, it was the same," she says. "You had all the similar issues: 'I'm not buying anything on the Internet because someone can steal my credit card number.'" Linden Lab's Yoon agrees. "When you first started to see the Internet as more than just education and government, you started seeing all these crap websites thrown up all over the place. It's sort of like the disorganized user-created content within Second Life," he says. "We saw that whole cycle in the development of the Internet—the cycle of doubt and fear, and realization that there is economic value, and communication and community value. We are seeing exactly the same thing happening again."

So far, not many complaints about virtual finance and commerce have surfaced in courtrooms. One—maybe the only one—revolved around a Pennsylvania lawyer named Marc Bragg, whose avatar went by the name Marc Woebegone. In 2005, Bragg signed up with Second Life and started whiling away his off hours amassing and reselling virtual land and selling virtual fireworks to other residents. He was doing quite well until May 2006, when Linden Lab accused him of manipulating an auction to acquire virtual land at a below-market price. The company shut down his account and confiscated all his virtual holdings; in so doing, it seized Linden dollars and property worth about $8,000. As the company saw it, Bragg broke the terms of service on his account, and his account was consequently canceled. Bragg felt he'd been robbed of real assets, not just a Second Life account, and so he took Linden Lab to court. He got his account and some of his belongings back in a recent settlement whose full terms were not disclosed.

The Bragg case—which hinged partly on Second Life's representations of virtual land as something that can be "owned"—showed that real-world authorities may not automatically dismiss virtual currency as Monopoly money, or in-world contracts as a game. But Ben Duranske says that other complaints, such as those of Ginko customers who say they lost money, have not yet elicited any governmental action. Duranske founded the Second Life Bar Association, an in-world community of real-world legal professionals and scholars, to explore questions of technology and the law. "If I did what the people of Ginko did—only using stamps and envelopes—it would be illegal, and easy to prove to a jury," he says.

VIRTUAL SOLUTIONS

In the summer of 2007, Linden Lab announced that to help make transactions more secure, it was creating a voluntary ID system, so that in-world consumers could verify attributes—such as the age—of the people behind the avatars they were dealing with. Another reason was to keep minors out of certain areas of Second Life; people under 18 are not allowed to sign up for accounts, and Linden has been trying to stamp out virtual sex between "adult" avatars and "child" avatars. The company also introduced algorithms that identify suspicious activity and warned users to be more prudent in their online dealings. "We caution our residents to be wary of anyone offering extremely high interest rates at no risk, either in the real world or in Second Life," the company's CFO, John Zdanowski, wrote in the Second Life blog (under the avatar name Zee Linden). "If it sounds too good to be true, it probably is."

Now users themselves are setting up some quasi-regulatory structures. Some have started the Second Life Exchange Commission, which sets standards for financial disclosure; others have created the Virtual World Business Bureau, which rates businesses, warns residents against scams, and acts as a clearinghouse for complaints. Just as a real-world company will seek affirmation of its credibility from PricewaterhouseCoopers, "the virtual environ-

ment absolutely has to be able to say you are a legitimate company doing legitimate business," IBM's Kearney says. "If you look at the 3-D Internet as the unformed future of the Internet, it will be very important to solve these problems."

Dan Miller, one of Capitol Hill's few experts on the subject of virtual economies (he's a staff economist with the Congressional Joint Economic Committee, working with the ranking member, Republican representative Jim Saxton of New Jersey), notes that different virtual worlds take different approaches to keeping transactions secure and transparent. Within Entropia Universe, every PED has a unique ID code and is tracked from its creation, through every transaction involving it, to the point at which the user cashes out by exchanging PEDs for real dollars. Linden dollars do not bear such codes, though the company says all transactions are monitored. Differences in transaction-tracking technologies could make it harder or easier for legal authorities to reconstruct alleged incidents of theft or fraud. But it also gives consumers a choice, Miller says: "If one virtual world likes the heavy-handed Big Brother controls to make everybody feel safe, that will appeal to certain people. If someone else is more of a caveat emptor person, they might go more toward another world." He warns that any government intervention to regulate commerce could be a slippery slope. "If the government starts regulating aspects for criminal purposes, they might start regulating the economic aspects," he says—by taxing virtual goods and services, for example.

David Naylor of Field Fisher Waterhouse, on the other hand, argues that if virtual worlds are going to attract more participants—and create a lucrative new front for e-commerce—they need real-world intervention. "The issue is that I don't think the authorities, in any jurisdiction, have really got their heads around Second Life," he says. "One reason is that it's brand-new technology. Or if they are familiar with it, they take the view that in terms of the potential damage, or potential losses, they've got bigger fish to fry." Cleaning up the situation "is going to take real-world regulators taking an interest," he says. "Watchdogs can't do it on their own. They can alert people to malpractice but can't provide compensation."

WILD WEST

Cornell's Robert Bloomfield is an experimental economist who conducts lab research—allowing 20 students to make simulated stock trades using real money, for example, and seeing how regulatory changes affect their behavior. He envisions a day when he can do larger studies by setting up parallel virtual worlds. "I could create two virtual worlds, one with one legal structure, one with another, and compare them," he says. "I might lower the capital-gains tax rate in one and see how business responds. There are things I can't do with 20 people in a classroom but I can do with 2,000 or 20,000 people in a virtual world."

Courts won't necessarily dismiss virtual currency as Monopoly money, or in-world contracts as a game. Says one lawyer, "If I did what the people of Ginko did, only using stamps and envelopes, it would be illegal, and easy to prove to a jury."

For now, though, he's studying what's actually happening among the 318,742 people who are spending money in Second Life. "It's pretty much the Wild West, and that makes it a fascinating place for study in its own right," Bloomfield says. "We just have to sort out what the best practices are, and the best practices involve a lot of transparency." Yoon, meanwhile, says he wouldn't be surprised if law enforcement was gearing up to prosecute some form of misdeed within virtual worlds, whether a financial scam or virtual pedophilia. "I have no doubt that that is going to be something that people are interested in looking into," he says. "It's not any different than Internet chat rooms as a collaboration medium. There are guys whose police beat it is to hang around in an Internet chat room, and to chase spam, and prevent those scams. I don't see why they wouldn't do this in virtual worlds."

To be sure, there are plenty of fleeced avatars who want their money back—and who are already backing away from the experiment that Bloomfield finds so promising. One of them is Rick Jones, a 47-year-old retired navy electronics technician who lives with a roommate in Oceanside, CA. In Second Life, he named his avatar Kiyotei Xi and bought and sold some land. "I had animals and fish and stuff that I would put around the land, for entertainment," he says. He makes art that he sells at another avatar's gallery, and he surfs in an area called Chi. But his experience has been marred, he says, by losing $460 in Ginko. He says he'd join a class action suit, though he wouldn't sue on his own. And has he lost his trust in in-world transactions? "Oh, heck yeah."

Stephanie Roberts has also lost some of her trust—but not enough to overwhelm her love for the possibilities she finds within Second Life. And certainly not enough for her to overlook the fact that there's nowhere in the virtual world to buy a digital Zamboni. Roberts is looking for someone to teach her how to design one, so she can start selling them to other residents—and do her own small part to expand the virtual economy. "Nobody else has built one yet," she says. "I could earn quite a bit off the sale of this thing!" TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

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Career Growth Profile

In 1995, Hee Sun Choung graduated from the University of Michigan and entered the workforce as a naval architect for Avineon in Alexandria, VA. In little more than a decade, she rose to the senior management level, overseeing some of the company's largest contracts. As the vice president of IT services, Choung now leads the development, management, and implementation of all federal civilian agency projects.

How did a twentysomething college graduate accelerate her career so quickly? Her boss, Avineon president and CEO Karlu Rambhala, cites Choung's commitment to continuing education as a major factor in her success. "The advanced degrees Hee Sun earned while being employed at Avineon have broadened her professional horizons," he says. "She has demonstrated a wider grasp of company financials and how the decisions she makes within the IT services division impact the overall growth and financial well-being of the company."

Choung says that at the start of her career, her undergraduate education provided the right combination of technical skills for designing marine vessels. However, as new technologies emerged and the company's operations evolved, she realized she needed more than her undergraduate degrees to stay afloat.

Hee Sun Choung

Age: 34
Job Title: Vice President of IT Services
Employer: Avineon
Program: MBA, Executive Program
George Washington University
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"You Don't Understand Our Audience"

WHAT I LEARNED ABOUT NETWORK TELEVISION AT *DATELINE NBC*

By JOHN HOCKENBERRY

The most memorable reporting I've encountered on the conflict in Iraq was delivered in the form of confetti exploding out of a cardboard tube. I had just begun working at the MIT Media Lab in March 2006 when Alyssa Wright, a lab student, got me to participate in a project called "Cherry Blossoms." I strapped on a backpack with a pair of vertical tubes sticking out of the top; they were connected to a detonation device linked to a Global Positioning System receiver. A microprocessor in the backpack contained a program that mapped the coördinates of the city of Baghdad onto those for the city of Cambridge; it also held a database of the locations of all the civilian deaths of 2005. If I went into a part of Cambridge that corresponded to a place in Iraq where civilians had died in a bombing, the detonator was triggered.

When the backpack exploded on a clear, crisp afternoon at the Media Lab, handfuls of confetti shot out of the cardboard tubes into the air, then fell slowly to earth. On each streamer of paper was written the name of an Iraqi civilian casualty. I had reported on the war (although not from Baghdad) since 2003 and was aware of persistent controversy over the numbers of Iraqi civilian dead as reported by the U.S. government and by other sources. But it wasn't until the moment of this fake explosion that the scale and horrible suddenness of the slaughter in Baghdad became vivid and tangible to me. Alyssa described her project as an upgrade to traditional journalism. "The upgrade is empathy," she said, with the severe humility that comes when you suspect you are on to something but are still uncertain you aren't being ridiculous in some way.

The falling confetti transported me back three years to the early days of the war in Iraq, when the bombs intended to evoke "shock and awe" were descending on Baghdad. Most of the Western press had evacuated, but a small contingent remained to report on the crumbling Iraqi regime. In the New York offices of NBC News, one of my video stories was being screened. If it made it through the screening, it would be available for broadcast later that evening. Producer Geoff Stephens and I had done a phone interview with a reporter in Baghdad who was experiencing the bombing firsthand. We also had a series of still photos of life in the city. The only communication with Baghdad in those early days was by satellite phone. Still pictures were sent back over the few operating data links.

Our story arranged pictures of people coping with the bombing into a slide show, accompanied by the voice of Melinda Liu, a *Newsweek* reporter describing, over the phone, the harrowing experience of remaining in Baghdad. The outcome of the invasion was still in doubt. There was fear in the reporter's voice and on the faces of the people in the pictures. The four-minute piece was meant to be the kind of package that would run at the end of an hour of war coverage. Such montages were often used as "enders," to break up the segments of anchors talking live to field reporters at the White House or the Pentagon, or retired generals who were paid to stand on in-studio maps and provide analysis of what was happening. It was also understood that without commercials there would need to be taped pieces on standby in case an anchor needed to use the bathroom. Four minutes was just about right.

At the conclusion of the screening, there were a few suggestions for tightening here and clarification there. Finally, an NBC/GE executive responsible for "standards" shook his head and wondered about the tone in the reporter's voice. "Doesn't it seem like she has a point of view here?" he asked.

There was silence in the screening room. It made me want to twitch, until I spoke up. I was on to something but uncertain I wasn't about to be handed my own head. "Point of view? What exactly do you mean by *point of view*?" I asked. "That war is bad? Is that the *point of view* that you are detecting here?"

Illustration by SEAN McCABE


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The story never aired. Maybe it was overtaken by breaking news, or maybe some pundit-general went long, or maybe an anchor was able to control his or her bladder. On the other hand, perhaps it was never aired because it contradicted the story NBC was telling. At NBC that night, war was, in fact, not bad. My remark actually seemed to have made the point for the "standards" person. Empathy for the civilians did not fit into the narrative of shock and awe. The lesson stayed with me, exploding in memory along with the confetti of Alyssa Wright's "Cherry Blossoms." Alyssa was right. Empathy was the upgrade. But in the early days of the war, NBC wasn't looking for any upgrades.

"THIS IS LONDON"

When Edward R. Murrow calmly said those words into a broadcast microphone during the London Blitz at the beginning of World War II, he generated an analog signal that was amplified, sent through a transatlantic cable, and relayed to transmitters that delivered his voice into millions of homes. Broadcast technology itself delivered a world-changing cultural message to a nation well convinced by George Washington's injunction to resist foreign "entanglements." Hearing Murrow's voice made Americans understand that Europe was close by, and so were its wars. Two years later, the United States entered World War II, and for a generation, broadcast technology would take Americans ever deeper into the battlefield, and even onto the surface of the moon. Communication technologies transformed America's view of itself, its politics, and its culture.

One might have thought that the television industry, with its history of rapid adaptation to technological change, would have become a center of innovation for the next radical transformation in communication. It did not. Nor did the ability to transmit pictures, voices, and stories from around the world to living rooms in the U.S. heartland produce a nation that is more sophisticated about global affairs. Instead, the United States is arguably more isolated and less educated about the world than it was a half-century ago. In a time of such broad technological change, how can this possibly be the case?

In the spring of 2005, after working in television news for 12 years, I was jettisoned from NBC News in one of the company's downsizings. The work that I and others at *Dateline NBC* had done—to explore how the Internet might create new opportunities for storytelling, new audiences, and exciting new mechanisms for the creation of journalism—had come to naught. After years of timid experiments, NBC News tacitly declared that it wasn't interested. The culmination of *Dateline*'s Internet journalism strategy was the highly rated pile of programming debris called *To Catch a Predator*. The *TCAP* formula is to post offers of sex with minors on the Internet and see whether anybody responds. *Dateline*'s notion of New Media was the technological equivalent of etching "For a good time call Sally" on a men's room stall and waiting with cameras to see if anybody copied down the number.

Networks are built on the assumption that audience size is what matters most. Content is secondary; it exists to attract passive viewers who will sit still for advertisements. For a while, that assumption served the industry well. But the TV news business has been blind to the revolution that made the viewer blink: the digital organization of communities that are anything but passive. Traditional market-driven media always attempt to treat devices, audiences, and content as bulk commodities, while users instead view all three as ways of creating and maintaining smaller-scale communities. As users acquire the means of producing and distributing content, the authority and profit potential of large traditional networks are directly challenged.

In the years since my departure from network television, I have acquired a certain detachment about how an institution so central to American culture could shift so quickly to the margins. Going from being a correspondent at *Dateline*—a rich source of material for *The Daily Show*—to working at the MIT Media Lab, where most students have no interest in or even knowledge of traditional networks, was a shock. It has given me some hard-won wisdom about the future of journalism, but it is still a mystery to me why television news remains so dissatisfying, so superficial, and so irrelevant. Disappointed veterans like Walter Cronkite and Dan Rather blame the moral failure of ratings-obsessed executives, but it's not that simple. I can say with confidence that Murrow would be outraged not so much by the networks' greed (Murrow was one of the first news personalities to hire a talent agent) as by the missed opportunity to use technology to help create a nation of engaged citizens bent on preserving their freedom and their connections to the broader world.

I knew it was pretty much over for television news when I discovered in 2003 that the heads of NBC's news division and entertainment division, the president of the network, and the chairman all owned TiVos, which enabled them to zap past the commercials that paid their salaries. "It's such a great gadget. It changed my life," one of them said at a corporate affair in the *Saturday Night Live* studio. It was neither the first nor the last time that a television executive mistook a fundamental technological change for a new gadget.

SETTING THE TABLE FOR *LAW AND ORDER*

On the first Sunday after the attacks of September 11, pictures of the eventual head of NBC littered the streets and stuffed the garbage cans of New York City; Jeff Zucker was profiled that week in the *New York Times Magazine*. The piles of newspapers from the weekend were everywhere at 30 Rockefeller Center. Normally, employee talk would have been about how

well or badly Zucker had made out in the *Times*. But the breezy profile was plainly irrelevant that week.

The next morning I was in the office of David Corvo, the newly installed executive producer of *Dateline*, when Zucker entered to announce that the network was going to resume the prime-time schedule for the first time since the attacks. The long stretch of commercial-free programming was expensive, and Zucker was certain about one thing: "We can't sell ads around pictures of Ground Zero." At the same time, he proceeded to explain that the restoration of the prime-time shows *Friends*, *Will and Grace*, and *Frasier* was a part of America's return to normalcy, not a cash-flow decision. He instructed Corvo that a series of news specials would be scattered through the next few days, but as it was impossible to sell ads for them, scheduling would be a "day to day" proposition.

Normally I spent little time near NBC executives, but here I was at the center of power, and I felt slightly flushed at how much I coveted the sudden proximity. Something about Zucker's physical presence and bluster made him seem like a toy action figure from *The Simpsons* or *The Sopranos*. I imagined that he could go back to his office and pull mysterious levers that opened the floodgates to pent-up advertisements and beam them to millions of households. Realistically, though, here was a man who had benefited from the timing of September 11 and also had the power to make it go away. In a cheap sort of way it was delirious to be in his presence.

At the moment Zucker blew in and interrupted, I had been in Corvo's office to propose a series of stories about al-Qaeda, which was just emerging as a suspect in the attacks. While well known in security circles and among journalists who tried to cover international Islamist movements, al-Qaeda as a terrorist organization and a story line was still obscure in the early days after September 11. It had occurred to me and a number of other journalists that a core mission of NBC News would now be to explain, even belatedly, the origins and significance of these organizations. But Zucker insisted that *Dateline* stay focused on the firefighters. The story of firefighters trapped in the crumbling towers, Zucker said, was the emotional center of this whole event. Corvo enthusiastically agreed. "Maybe," said Zucker, "we ought to do a series of specials on firehouses where we just ride along with our cameras. Like the show *Cops*, only with firefighters." He told Corvo he could make room in the prime-time lineup for firefighters, but then smiled at me and said, in effect, that he had no time for any subtitled interviews with jihadists raging about Palestine.

With that, Zucker rushed back to his own office, many floors above *Dateline*'s humble altitude. My meeting with Corvo was basically over. He did ask me what I thought about Zucker's idea for a reality show about firefighters. I told him that we would have to figure a way around the fact that most of the time very little actually happens in firehouses. He nodded and muttered something about seeking a lot of "back stories" to maintain an emotional narrative. A few weeks later, a half-dozen producers were assigned to find firehouses and produce long-form documentaries about America's rediscovered heroes. Perhaps two of these programs ever aired; the whole project was shelved very soon after it started. Producers discovered that unlike September 11, most days featured no massive terrorist attacks that sent thousands of firefighters to their trucks and hundreds to tragic, heroic deaths. On most days nothing happened in firehouses whatsoever.

This was one in a series of lessons I learned about how television news had lost its most basic journalistic instincts in its search for the audience-driven sweet spot, the "emotional center" of the American people. Gone was the mission of using technology to veer out onto the edge of American understanding in order to introduce something fundamentally new into the national debate. The informational edge was perilous, it was unpredictable, and it required the news audience to be willing to learn something it did not already know. Stories from the edge were not typically reassuring about the future. In this sense they were like actual news, unpredictable flashes from the unknown. On the other hand, the coveted emotional center was reliable, it was predictable, and its story lines could be duplicated over and over. It reassured the audience by telling it what it already knew rather than challenging it to learn. This explains why TV

The TV news business has been blind to the revolution that made the viewer blink: the digital organization of communities that are anything but passive. As users acquire the means of producing and distributing content, the authority and profit potential of large traditional networks are directly challenged.

news voices all use similar cadences, why all anchors seem to sound alike, why reporters in the field all use the identical tone of urgency no matter whether the story is about the devastating aftermath of an earthquake or someone's lost kitty.

It also explains why TV news seems so archaic next to the advertising and entertainment content on the same networks. Among the greatest frustrations of working in TV news over the past decade was to see that while advertisers and entertainment producers were permitted to do wildly risky things in pursuit of audiences, news producers rarely ventured out of a safety zone of crime, celebrity, and character-driven tragedy yarns.

Advertisers were aggressive in their use of new technologies long before network news divisions went anywhere near them. This is exactly the opposite of the trend in the 1960s and '70s, when the news divisions were first adopters of breakthroughs in live satellite and video technology. But in the 1990s, advertisers were quick to use the Internet to seek information about consumers, exploiting the potential of communities that formed around products and brands. Throughout the time I was at the network, GE ads were all over NBC programs like *Meet the Press* and CNBC's business shows, but they seemed never to appear on *Dateline*. (They also had far higher production values than the news programs and even some entertainment shows.) Pearl Jam, Nirvana, and N.W.A were already major cultural icons; grunge and hip-hop were the soundtrack for commercials at the moment networks were passing on stories about Kurt Cobain's suicide and Tupac Shakur's murder.

Meanwhile, on *60 Minutes*, Andy Rooney famously declared his own irrelevance by being disgusted that a spoiled Cobain could find so little to love about being a rock star that he would kill himself. Humor in commercials was hip—subtle, even, in its use of obscure pop-cultural references—but if there were any jokes at all in news stories, they were telegraphed, blunt visual gags, usually involving weathermen. That disjunction remains: at the precise moment that Apple cast John Hodgman and Justin Long as dead-on avatars of the PC and the Mac, news anchors on networks that ran those ads were introducing people to multibillion-dollar phenomena like MySpace and Facebook with the cringingly naïve attitude of "What will those nerds think of next?"

Entertainment programs often took on issues that would never fly on *Dateline*. On a Thursday night, *ER* could do a story line on the medically uninsured, but a night later, such a "downer policy story" was a much harder sell. In the time I was at NBC, you were more likely to hear federal agriculture policy discussed on *The West Wing*, or even on Jon Stewart, than you were to see it reported in any depth on *Dateline*.

Sometimes entertainment actually drove selection of news stories. Since *Dateline* was the lead-in to the hit series *Law & Order* on Friday nights, it was understood that on Fridays we did crime. Sunday was a little looser but still a hard sell for news that wasn't obvious or close to the all-important emotional center. In 2003, I was told that a story on the emergence from prison of a former member of the Weather Underground, whose son had graduated from Yale University and won a Rhodes Scholarship, would not fly unless it dovetailed with a story line on a then-struggling, soon-to-be-cancelled, and now-forgotten Sunday-night drama called *American Dreams*, which was set in the 1960s. I was told that the Weather Underground story might be viable if *American Dreams* did an episode on "protesters or something." At the time, *Dateline*'s priority was another series of specials about the late Princess Diana. This blockbuster was going to blow the lid off the Diana affair and deliver the shocking revelation that the poor princess was in fact even more miserable being married to Prince Charles than we all suspected. Diana's emotional center was coveted in prime time even though its relevance to anything going on in 2003 was surely out on some voyeuristic fringe.

To get airtime, not only did serious news have to audition against the travails of Diana or a new book by Dr. Phil, but it also had to satisfy bizarre conditions. In 2003, one of our producers obtained from a trial lawyer in Connecticut video footage of guards subduing a mentally ill prisoner. Guards themselves took the footage as part of a safety program to ensure that deadly force was avoided and abuses were documented for official review. We saw guards haul the prisoner down a greenish corridor, then heard hysterical screaming as the guard shooting the video dispassionately announced, "The prisoner is resisting." For 90 seconds several guards pressed the inmate into a bunk. All that could be seen of him was his feet. By the end of the video the inmate was motionless. Asphyxiation would be the official cause of death.

This kind of gruesome video was rare. We also had footage of raw and moving interviews with this and another victim's relatives. The story had the added relevance that one of the state prison officials had been hired as a consultant to the prison authority in Iraq as the Abu Ghraib debacle was unfolding. There didn't seem to be much doubt about either the newsworthiness or the topicality of the story. Yet at the conclusion of the screening, the senior producer shook his head as though the story had missed the mark widely. "These inmates aren't necessarily sympathetic to our audience," he said. The fact that they had been diagnosed with schizophrenia was unimportant. Worse, he said that as he watched the video of the dying inmate, it didn't seem as if anything was wrong.

"Except that the inmate died," I offered.

"But that's not what it looks like. All you can see is his feet."

"With all those guards on top of him."

"Sure, but he just looks like he's being restrained."

"But," I pleaded, "the man died. That's just a fact. The prison guards shot this footage, and I don't think their idea was to get it on *Dateline*."

"Look," the producer said sharply, "in an era when most of our audience has seen the Rodney King video, where you can clearly see someone being beaten, this just doesn't hold up."

"Rodney King wasn't a prisoner," I appealed. "He didn't die, and this mentally ill inmate is not auditioning to be the next Rodney King. These are the actual pictures of his death."

"You don't understand our audience."

"I'm not trying to understand our audience," I said. I was getting pretty heated at this point—always a bad idea. "I'm doing a story on the abuse of mentally ill inmates in Connecticut."

"You don't get it," he said, shaking his head.

The story aired many months later, at less than its original length, between stories that apparently reflected a better understanding of the audience. During my time at *Dateline*, I did plenty of stories that led the broadcast and many full hours that were heavily promoted on the network. But few if any of my stories were more tragic, or more significant in news value, than this investigation into the Connecticut prison system.

Networks have so completely abandoned the mission of reporting the news that someone like entrepreneur Charles Ferguson, who sold an Internet software company to Microsoft in 1996 *[and whose writing has appeared in this magazine; see "What's Next for Google," January 2005 —Ed.]*, can spend $2 million of his own money to make an utterly unadorned documentary about Iraq and see it become an indie hit. Ferguson's *No End in Sight* simply lays out, without any emotional digressions or narrative froth, how the U.S. military missed the growing insurgency. The straightforward questions and answers posed by this film are so rare in network news today that they seem like an exotic, innovative form of cinema, although they're techniques that belong to the Murrow era. In its way, Ferguson's film is as devastating an indictment of network television as it is of the Bush administration.

MISFIRES

Even when the networks do attempt to adopt new technology, they're almost as misguided as when they don't. As the nation geared up for the invasion of Iraq back in 2002 and 2003, NBC seemed little concerned with straightforward questions about policy, preparedness, and consequences. It was always, on some level, driven by the unstated theme of 9/11 payback, and by the search for the emotional center of the coming conflict. From the inside, NBC's priority seemed to be finding—and making sure the cameras were aimed directly at—the September 11 firefighters of the coming Iraq invasion: the soldiers. To be certain, the story of the troops was newsworthy, but as subsequent events would reveal, focusing on it so single-mindedly obscured other important stories.

In 2002 and 2003, NBC news spent enormous amounts of time and money converting an army M88 tank recovery vehicle into an armored, mobile, motion-stabilized battlefield production studio. The so-called Bloom-mobile, named for NBC correspondent David Bloom, brought a local, Live-at-5, "This is London" quality to armed conflict. Using a microwave signal, the new vehicle beamed pictures of Bloom, who was embedded with the Third Infantry Division, from the Iraqi battlefield to an NBC crew a few miles behind, which in turn retransmitted to feed via satellite to New York, all in real time. While other embeds had to report battlefield activities, assemble a dispatch, and then transport it to a feed point at the rear of the troop formation, Bloom could file stories that were completely live and mostly clear. He became a compelling TV surrogate for all the soldiers, and demand for his "live shots" was constant.

But Bloom's success in conveying to the viewing audience the visual (and emotional) experiences of the advancing troops also meant that he was tethered to his microwave transmitter and limited in his ability to get a bigger picture of the early fight. Tragically, Bloom died of a deep-vein blood clot. The expensive Bloom-mobile remote transmitter eventually came home and spent time ghoulishly on display outside 30 Rockefeller Center. It was used once or twice to cover hurricanes in the fall of 2004, to little success, and was eventually mothballed. The loss of one of NBC's most talented journalists was folded into the larger emotional narrative of the war and became a way of conveying, by implication, NBC's own casualty count in the war effort.

The focus on gadgetry meant once again that the deeper story about technology and the war was missed. Technology was revolutionizing war reporting by enabling combat soldiers to deliver their own dispatches from the field in real time. In 2004, I pitched *Dateline* on the story of how soldiers were creating their own digital networks and blogging their firsthand experiences of the war. The show passed. My story appeared in *Wired* a year later.

SIX SIGMA IN THE NEWSROOM

Perhaps the biggest change to the practice of journalism in the time I was at NBC was the absorption of the news division into the pervasive and all-consuming corporate culture of GE. GE had acquired NBC back in 1986, when it bought RCA. By 2003, GE's managers and strategists were getting around to seeing whether the same tactics that made the production of turbine generators more efficient could improve the production of television news. This had some truly bizarre consequences.

To say that this *Dateline* correspondent with the messy corner office greeted these internal corporate changes with self-destructive skepticism is probably an understatement.

Six Sigma—the methodology for the improvement of business processes that strives for 3.4 defects or fewer per million opportunities—was a somewhat mysterious symbol of management authority at every GE division. Six Sigma messages popped up on the screens of computers or in e-mail in-boxes every day. Six Sigma was out there, coming, unstoppable, like a comet or rural electrification. It was going to make everything better, and slowly it would claim employees in glazed-eyed conversions. Suddenly in the office down the hall a coworker would no longer laugh at the same old jokes. A grim smile suggested that he was on the lookout for snarky critics of the company. It was better to talk about the weather.

While Six Sigma's goal-oriented blather and obsession with measuring everything was jarring, it was also weirdly familiar, inasmuch as it was strikingly reminiscent of my college Maoism I class. Mao seemed to be a good model for Jack Welch and his Six Sigma foot soldiers; Six Sigma's "Champions" and "Black Belts" were Mao's "Cadres" and "Squad Leaders."

Finding such comparisons was how I kept from slipping into a coma during dozens of NBC employee training sessions where we were told not to march in political demonstrations of any kind, not to take gifts from anyone, and not to give gifts to anyone. At mandatory, hours-long "ethics training" meetings we would watch in-house videos that brought all the drama and depth of a driver's-education film to stories of smiling, swaggering employees (bad) who bought cases of wine for business associates on their expense accounts, while the thoughtful, cautious employees (good) never picked up a check, but volunteered to stay at the Red Roof Inn in pursuit of "shareholder value."

To me, the term "shareholder value" sounded like Mao's "right path," although this was not something I shared at the employee reëducation meetings. As funny as it seemed to me, the idea that GE was a multinational corporate front for Maoism was not a very widespread or popular view around NBC. It was best if any theory that didn't come straight from the NBC employee manual (a Talmudic tome that largely contained rules for using the GE credit card, most of which boiled down to "Don't") remained private.

I did, however, point out to the corporate-integrity people unhelpful details about how NBC News was covering wars in Iraq and Afghanistan that our GE parent company stood to benefit from as a major defense contractor. I wondered aloud, in the presence of an integrity "team leader," how we were to reconcile this larger-scale conflict with the admonitions about free dinners. "You make an interesting point I had not thought of before," he told me. "But I don't know how GE being a defense contractor is really relevant to the way we do our jobs here at NBC news." Integrity, I guess, doesn't scale.

Other members of the "GE family" had similar doubts about their relevance to the news division. In early 2002, our team was in Saudi Arabia covering regional reaction to September 11. We spent time on the streets and found considerable sympathy for Osama bin Laden among common citizens at the same time that the Saudi government expressed frustration that Americans seemed not to consider it an ally in the war on terror. We tracked down relatives of the September 11 hijackers, some of whom were deeply shocked and upset to learn what their family members had done. We wanted to speak with members of Osama bin Laden's family about their errant son's mission to bring down the Saudi government and attack the infidel West. We couldn't reach the bin Ladens using ordinary means, and the royal family claimed that it had no real clout with the multibillion-dollar bin Laden construction giant that built mosques, roads, and other infrastructure all over the world.

Big-screen TVs and downloadable episodes of *Late Night with Conan O'Brien* are merely more attempts to control the means of distribution, something GE has been doing since the invention of the light bulb.

But GE had long done business with the bin Ladens. In a misguided attempt at corporate synergy, I called GE headquarters in Fairfield, CT, from my hotel room in Riyadh. I inquired at the highest level to see whether, in the interest of bringing out all aspects of an important story for the American people, GE corporate officers might try to persuade the bin Ladens to speak with *Dateline* while we were in the kingdom. I didn't really know what to expect, but within a few hours I received a call in my hotel room from a senior corporate communications officer who would only read a statement over the phone. It said something to the effect that GE had an important, long-standing, and valuable business relationship with the Bin Laden Group and

saw no connection between that relationship and what *Dateline* was trying to do in Saudi Arabia. He wished us well. We spoke with no bin Laden family member on that trip.

In the end, perhaps the work that I was most proud of at NBC marginalized me within the organization and was my undoing. I had done some of the first live Internet audio and video webcasts on MSNBC. I anchored live Web broadcasts from the political conventions in 2000 when such coverage was just beginning. I helped produce live interactive stories for *Dateline* where the audience could vote during commercial breaks on how a crime mystery or a hostage situation would turn out. I loved what we could do through the fusion of TV and the Internet. During one interactive broadcast, I reported the instant returns from audience surveys live in the studio, with different results for each time zone as *Dateline* was broadcast across the country. Sitting next to me, Stone Phillips (not a big fan of live TV) would interact with me in that chatty way anchors do. Stone decided that rather than react naturally to the returns from the different time zones, he would make a comment about how one hostage-negotiator cop character in the TV story reminded him of Dr. Phil. He honed the line to the point that he used the exact same words for each time zone. "I think the Dr. Phil line is working, don't you?" he asked, as though this was his reporting-from-the-rooftops-of-London moment. "Sure, Stone." I said. "It's working great."

Phillips was hardly alone in his reaction to the new technology that was changing television, and in the end we were both dumped by NBC anyway. When I got the word that I'd been axed, I was in the middle of two projects that employed new media technology. In the first, we went virtually undercover to investigate the so-called Nigerian scammers who troll for the gullible with (often grammatically questionable) hard-luck stories and bogus promises of hidden millions. We descended into the scammers' world as a way of chasing them down and also illustrating how the Internet economy works. With search techniques and tracing strategies that reveal how Internet traffic is numerically coded, we chased a team of con artists to a hotel in Montreal, where we nailed them on hidden camera. With me playing the patsy, the story showed, in a very entertaining and interesting way, how the mechanics of the Internet worked to assist criminals. The second story unearthed someone who spammed people with porn e-mails. It was a form of direct-mail advertising that paid decent money if you had the right e-mail lists. The spammers didn't get involved with the porn itself; they just traded in e-mail lists and hid behind their digital anonymity. We exposed one of these spammers and had him apologize on camera, without spectacle, to a Dallas housewife to whom he had sent hard-core e-mails. The story wasn't merely about porn and spammers; it showed how electronic media gave rise to offshore shadow companies that traded e-mail lists on a small but very effective scale. The drama in the story was in seeing how we could penetrate spammers' anonymity with savvy and tenacity while educating people about technology at the same time. It was admittedly a timid effort that suggested the barest glimpse of new media's potential, but it was something.

Dateline started out interested but in the end concluded that "it looks like you are having too much fun here." David Corvo asked us to go shoot interviews of random people morally outraged by pornographic e-mails to "make it clear who the bad guys are." As might have been predicted, he was sending us back to find the emotional center after journalistic reality, once again, had botched the audition. I had long since cleaned out my office when the stories finally aired. *Dateline* eventually found the emotional center with *To Catch a Predator*, which had very little to do with Internet technology beyond 1990s-era chat rooms. What it did have was a supercharged sense of who the bad guys were (the upgrade for my spammer's simple apology was having the exposed predators hauled off to jail on camera) and a superhero in the form of grim reaper Chris Hansen, who was now a star.

I moved on. My story for *Wired* on bloggers from the Iraq War landed me an appearance on *The Daily Show*. Jon Stewart bluntly asked me what it's like to be at *Dateline* for nine years: "Does it begin to rot you from the inside?" The audience seemed not entirely convinced that this was a joke. They were actually interested in my answer, as though I were announcing the results of a medical study with wide implications for human health. I had to think about this rotting-from-the-inside business. I dodged the question, possibly because it was the one I had been asking myself for most of those nine years. But the answer is that I managed not to rot.

Life at the Media Lab has reminded me once again that technology is most exciting when it upsets the status quo. Big-screen TVs and downloadable episodes of *Late Night with Conan O'Brien* are merely more attempts to control the means of distribution, something GE has been doing since the invention of the light bulb. But exploding GPS backpacks represent an alien mind-set; they are part of the growing media insurgency that is redefining news, journalism, and civic life. This technological insurgency shouldn't surprise us: after all, it's wrapped up in language itself, which has long defied any attempt to commodify it. Technology, as it has done through the ages, is freeing communication, and this is good news for the news. A little empathy couldn't hurt. TR

JOHN HOCKENBERRY IS A DISTINGUISHED FELLOW AT THE MIT MEDIA LAB AND THE COHOST OF A MULTIPLATFORM MORNING NEWS PROGRAM ON PUBLIC RADIO LAUNCHING LATER THIS YEAR.

REVIEWS

PROSTHETICS

The Naked Ear

A FULLY IMPLANTABLE HEARING AID IS SHOWING PROMISE.

By MICHAEL CHOROST

A hearing aid is a straightforward device. Its microphone collects sound, its electronics amplify it, its tiny loudspeaker sends the sound into a tube placed in the ear canal, and the power comes from a disposable battery. There's just one problem: people hate hearing aids. They get lost. They're hard to wear while sleeping. They mustn't get wet. They get chewed up by the dog. They're awkward during sex.

I don't have a hearing aid. But I do have a cochlear implant. Cochlear implants are for people who are so deaf that even the most powerful hearing aids won't help. A processor worn on my ear collects sound and digitizes it, then transmits it by radio to a receiver embedded in my skull. The receiver sends pulses to electrodes attached to my auditory nerves.

CARINA FULLY IMPLANTABLE HEARING DEVICE
Otologics
$20,000 upon FDA approval; otologics.com

It should be called a cochlear *semi*-implant, really, because half of it is on the outside. It lets me hear, which is great, but it has the same disadvantages as hearing aids. For starters, I have to assemble myself in the morning—literally. But more than that, my cochlear implant feels like something decidedly *attached* to me. Naturally, I would love to have a body that's whole and complete in itself. A body that could plunge into the water without sacrificing the ability to hear friends' laughter when it emerged.

So far, no one's built a fully implantable cochlear implant. But two fully implantable hearing aids are now in clinical trials (that is to say, they are considered investigational by the U.S. Food and Drug Administration and are not yet approved for commercial sale). One, the Esteem, is built by Envoy Medical of St. Paul, MN. The other, from Otologics of Boulder, CO, is called the Carina. Hopes are high that they will be the first successful devices of their kind. Making such things is a challenge. Where does the microphone go? How is the amplified sound sent into the ear? What's the power source? And how can it be kept in the body without leaking?

I was curious to know whether the new devices worked as well as conventional hearing aids. I was even more curious to know whether the technology could be applied to cochlear implants. Otologics was game to show me its work.

LUCKY YORICK

At Otologics, Brian Conn, the engineering director, brought out a skull with the company's device bolted onto it. I realized after a queasy moment that it was a *real* skull.

The device didn't look like a hearing aid. There were four connected pieces designed to be countersunk into the skull.

The first piece, the microphone, sat behind the outer ear. The sensitivity of a microphone drops by a factor of 10 when it's buried under skin, so to compensate, the microphone had a surface area 10 times as big as a hearing aid's. It was about the size of a fingernail. Its output went to the biggest component, the processing unit. Its shell also contained a rechargeable lithium-ion battery.

The battery was recharged, Conn told me, by the third component: an inductive coil. An inductive coil converts radio waves into electricity. For an hour or two a day, the user puts a small radio transmitter up against the coil. Since both the coil and the transmitter have magnets in them, they stick together through the skin. The patient can walk around wearing the charging unit until the battery is full.

The fourth component was a vibrating piston in the middle ear, secured by four titanium bolts screwed to the skull. This was what actually delivered the sound. The middle ear consists of three tiny bones that conduct vibrations from the eardrum to the inner ear. The piston moved the bones more forcefully than the eardrum would, so it acted as an amplifier.

I peered at the skull, feeling like Hamlet contemplating a high-tech Yorick. The Carina was a strange-looking gadget. Big, too: at about five inches long, it stretched from behind the ear to just behind the temple. The surgery would involve opening a skin flap, drilling into the skull to countersink the components, and then drilling into the middle ear to install the piston. A lot of hardware to get into place.

THE CARINA, a fully implantable hearing aid from Boulder-based Otologics, is in clinical trials.

"How long does the battery last?" I asked.

Each charge was good for about a day, Conn told me. The battery could go through enough charge cycles to last at least five years, and possibly 10 or more.

"And when the battery can't hold a charge anymore?" I asked.

When that happened, Conn told me, the entire device, except for the piston, would be replaced. The microphone, coil, and processor had many connections to each other, so they had to be hermetically sealed together to keep body fluids out. The piston had only two connections, though, so a seal could be maintained between them. In any case, the surgery would be simple. Pull out the old unit. Snap in the new one.

"Wow," I said to Yorick.

THE $20,000 QUESTION

Otologics arranged for me to speak with a Carina user in Hamburg, Germany, a 25-year-old medical student named Veronika Koch. I called her from the company's conference room, aware that the situation was full of acoustical land mines. A totally deaf American was going to speak to a mostly deaf German through a speakerphone and across a language barrier.

But we understood each other with very little trouble. Veronika said she loved having a fully implanted device: "You don't have to think about it. That's the most important thing. When it was turned on, it was one of the most beautiful experiences I ever had. Nothing touching my ear. That natural feeling of hearing—it's just beautiful."

I asked her how the Carina sounded. "Sound quality is one of the biggest advantages," she said. "Speech quality is good and more natural, and music is very beautiful."

Veronika was clearly pleased. But I knew that Otologics would have given me its star patient. That's why the FDA puts new products through clinical trials—to get an objective look at their performance. What do the Carina's clinical trials show?

The device is now in phase II trials. (Phase I trials, conducted on a small group, test for safety; phase II, which involve a slightly larger group, tests for effectiveness; and phase III assesses both safety and effectiveness in a large group.) Results of the phase I trial had been ambiguous. In controlled hearing tests, its 20 subjects had scored somewhat worse with the Carina than they had with their own hearing aids, particularly in their ability to hear soft sounds. In a written survey to measure subjective impressions of the device, on the other hand, subjects had said, consistently, that they heard better with the Carina.

But still, the company wanted to see whether the phase II patients could get better results on the tests. They theorized that if the surgeons put the microphone in a specific spot behind the ear where there were fewer scalp muscles, soft sounds would not be masked so much.

So far, the phase II study has enrolled only 12 of the 70 to 80 users it needs, so its results are preliminary. But Herman Jenkins, the primary investigator, told me that the new microphone placement seems to be working. The phase II patients can hear a 3,000-hertz tone (a common frequency in speech) at a volume of 37 decibels, whereas the phase I subjects could hear it only at 55 decibels. This is a significant improvement; 37 decibels is about the ambient sound level of a library, whereas 55 decibels is the approximate level of conversational speech. And nine of the patients got word recognition scores that averaged 82 percent, statistically matching the 84 percent they got with their conventional hearing aids.

It would be a great achievement if an implanted hearing aid could match a conventional one. The question would then become, At four times the cost, is it worth it? Neither a high-end conventional aid, at $5,000, nor the Carina, at $20,000, is covered by insurance. And of course, if the patient got two, the price would double. (Surgeons currently

PETER BELANGER

implant the aids in only one ear to minimize risk, but once the devices prove themselves, patients may opt for two.)

Otologics hoped that the military, at any rate, would think it worth the cost. Jim Easter, the company's director of business development, explained to me that military jets are much louder than they used to be. Ear protection helps only a little; the whole skull vibrates. Pilots and ground crew are going deaf in alarming numbers.

A conventional aid, Easter said, might be okay for a desk jockey, but not for a pilot who has to wear headgear, execute high-G maneuvers, and possibly end up in the water. And not for a crew member who sweats like crazy on a hot flight deck. He thought the military would like a device that went inside the body and stayed there.

And what about me, with my decidedly one-G writer's life? Could the technology be used in cochlear implants?

The main challenge, Conn said, would be to substitute an electrode array in the inner ear for the piston the Carina uses in the middle ear. It might be possible to create a detachable electrode that would stay in place when the unit needed to be replaced, but that would require maintaining a seal with as many as 30 separate connections. Still, Conn thought it could be done.

On the way home, I thought about the pros and cons of the Carina. Four times the price. Surgery—and not just once, but every five or 10 years. On the other hand, quite possibly better hearing. Being able to hear while swimming, sleeping, and showering. Having a body that looked normal—*felt* normal. If I were a hearing-aid user, would I do it?

I'd want to see good results over a longer period of time first: the complete FDA testing and findings. I'd want to see patients doing well with the device for a while after it hit the market. And I'd need to have a spare 20 grand lying around.

But given all that, the answer is yes, I probably would. TR

MICHAEL CHOROST IS THE AUTHOR OF *REBUILT: HOW BECOMING PART COMPUTER MADE ME MORE HUMAN*, A MEMOIR OF GETTING A COCHLEAR IMPLANT.

AGRONOMY

Green Revolutionary

FOUR DECADES AGO, NORMAN E. BORLAUG DEVELOPED A WHEAT VARIETY THAT FED THE WORLD. NOW HE'S BATTLING AN OLD ENEMY: A PATHOGEN WHOSE SPREAD COULD CAUSE STARVATION.

By JOHN POLLOCK

In 1798, the English economist Thomas Malthus argued that population increases geometrically, outstripping the arithmetic growth of the food supply. He promised "famine ... the last, the most dreadful resource of nature." It took another 125 years for world population to double, but only 50 more for it to redouble. By the 1940s, Mexico, China, India, Russia, and Europe were hungry. Franklin D. Roosevelt's far-sighted vice president–elect, former secretary of agriculture Henry A. Wallace, believed the solution lay with technology. He was right: the Malthusian tragedy never happened, chiefly because Norman E. Borlaug transformed the breeding of wheat, which feeds more people than any other crop.

THE MAN WHO FED THE WORLD: NOBEL PEACE PRIZE LAUREATE NORMAN BORLAUG AND HIS BATTLE TO END WORLD HUNGER
Leon Hesser
Durban House, 2006, $24.95

From 1939 to 1942, Mexico's harvest was halved by stem rust, a fungus whose airborne spores infect stems and leaves, shriveling grains. Anxieties about wartime food shortages led the American philanthropic organization the Rockefeller Foundation to create the country's first foreign agricultural program: the Coöperative Wheat Research and Production Program, which was based in Mexico and which Borlaug joined, as its plant pathologist, in 1944. The program was prescient: rust hit the North American breadbasket in 1954, wiping out 75 percent of the durum wheat crop used for pasta.

"There was panic in the U.S. and Canadian departments of agriculture," Borlaug tells me. "We had to accelerate the program to develop rust-resistant wheat varieties." Borlaug struggled with a lack of machinery, equipment, and trained scientists. Yet by 1948, he tells Leon Hesser in *The Man Who Fed the World*, a recent biography, "research results, the bits and pieces of the wheat production puzzle, began to emerge, and the fog of gloom and despair began to lift."

Before Borlaug, plant breeders sought new traits in plants by creating perhaps a few dozen "crosses" of varieties each year. For Borlaug, this would have meant "at least 10 years developing resistant varieties," he recalls, "and there would be another epidemic in that time. I

ART RICKERBY/TIME LIFE PICTURES/GETTY IMAGES

wanted to speed things up." Collecting wheat varieties from around the world, he began a massive cross-breeding program. Such work is "mind-warpingly tedious," he tells Hesser. "There's only one chance in thousands of ever finding what you want, and actually no guarantee of success at all."

To improve those odds, Borlaug tried something unusual: doing two successive plantings of his experimental crosses each year, effectively doubling his rate of research. He was almost stymied by what he calls "the dogma of plant breeding everywhere at the time: plant in the same season and place as local farmers." But soon he was planting in summer in low-quality, rain-fed soils at high altitude near Mexico City, and then taking any promising varieties hundreds of miles north to sow a winter crop in the warmer, drier, lower-lying Yaqui Valley. This "shuttle breeding" helped Borlaug achieve rust resistance in under five years. It also produced exceptionally adaptable varieties, suited for use across climates.

Having achieved rust resistance and plant adaptability, Borlaug now addressed the problem of structure. When Mexican wheat was heavily fertilized, it grew too tall, collapsing when irrigated or rained on—thus limiting yields. After 20,000 fruitless crosses, Borlaug heard about a Japanese dwarf variety that might confer its strength and stockiness. He started thousands more crosses, until "by 1964, we got the really beautiful short wheat varieties." The yields were spectacular, and the variety was quickly adopted around world. In 1968, his approach, which stimulated advances in other staple foods, was dubbed the "Green Revolution" by William Gaud, administrator of the U.S. Agency for International Development. Two years later, Borlaug won the Nobel Peace Prize.

Paradoxically, 1968 also saw the genesis of an environmentalist dogma that was pessimistic about humanity's capacity to feed itself. In that year—when the global population growth rate peaked, at 2 percent per year—Paul Ehrlich published *The Population Bomb,* intoning, "The battle to feed all of humanity is over. ... Hundreds of millions of people will starve to death in spite of any crash programs." The madding crowd of "stinking hot" Delhi was odious to Ehrlich: "My wife and daughter and I ... entered a crowded slum area. ... People, people, people, people. ... [We] were, frankly, frightened." It was a "fantasy," he said, that India would ever feed itself. Yet Borlaug's program delivered such stunning results that India issued a 1968 stamp commemorating the "wheat revolution," and by 1974 it was self-sufficient in all cereals.

Nonetheless, a neo-Malthusian fear of overpopulation became endemic to environmentalist thinking. Science philosopher and *Arts and Letters Daily* founder Denis Dutton says, "Well-fed Greens flaunt their concern for the planet but are indifferent, even hostile, to the world's poor with whom they share it. Some Greens I knew acted for all the world as though they relished the idea of a coming worldwide famine, much as fundamentalists ghoulishly looked forward to Armageddon." Dutton, who served in the Peace Corps, personally saw the Green Revolution benefit India. "For the catastrophist, India becoming a food exporter was disturbing," he says. "This wasn't supposed to happen. They blame Borlaug for spoiling the fun."

Not all Borlaug's critics were catastrophists: some opposed the intensity of his agriculture, especially its use of inorganic fertilizer. Borlaug acknowledges the need for care, but he says the "natural" alternative, cow manure, "would require us to increase the world's cattle population from around 1.5 billion to some 10 billion." As he dryly observed in a 2003 TV interview, "Producing food for 6.2 billion people ... is not simple." He added, "[Organic approaches] can only feed four billion—I don't see two billion volunteers to disappear."

Raised on a farm, Borlaug thinks many of his detractors would benefit from a week or two in the fields. He cites Ghanaian farmers who use no-till agriculture (that is, plant waste is left to improve the humus and reduce erosion) and control weeds with herbicides. Their lives are improved by the reduction in weeding. "Less backache, you see," he once said. "You know, it's amazing how often campaigners in rich countries think poor people don't get backache."

A NEW SCOURGE

Many thought the work that earned Borlaug his Nobel brought an end to stem rust, but it is back, in the form of a variant called Ug99, which emerged in Uganda and spread to Kenya and Ethiopia. "If it continues unchecked," says Borlaug, "the consequences will be ruinous."

Africa, in fact, presents an especially worrying challenge, for the simple reason that it did not benefit much from the Green Revolution. Borlaug's Nobel largely honored gains in Asia: there, calorie availability per person rose, wheat and rice prices fell, and increased incomes stimulated industrial output. Similar benefits were enjoyed almost everywhere except sub-Saharan Africa, where more than 200 million people—a third of the population—still go hungry. In the last four decades, Africa's average per capita food production has actually decreased.

Ug99 will be fought, at least initially, with the plant-breeding techniques Borlaug so artfully employed. However, he believes Africa's best hopes rest with biotechnology, even though regulatory problems prevent its immediate use against Ug99. Also needed, he believes, are publicity, political will, funding, and renewed coöperation among international agricultural researchers. The work he is inspiring is nothing less than a new African Green Revolution.

The reasons for failure in Africa are complex. "Irrigation is first," explains Michael Lipton of the University of Sussex's Poverty Research Unit. "In sub-Saharan Africa, 4 percent of cropland is irrigated. In South and East Asia it's nearer 40 percent."

Then there's soil. "Africa's soils ... [are] equivalent—and were once adjacent—to the Cerrado's acid soils," Borlaug says. The Cerrado, an area that extends across central Brazil, historically had some of the least productive soil in the world. But improved crop varieties of the sort that Borlaug created—along with

liming, fertilizer, and low- or no-till methods—have led to the single largest increase in arable-land usage in the last 50 years.

Politics, both regional and global, were and are another hindrance. "If the Green Revolution in India was proposed to the World Bank today, it would be turned down," says Rob Paarlberg, an agricultural-policy expert at Wellesley College. By the 1980s, he says, "public investment in roads, research, irrigation, fertilizers, and seeds was politically unacceptable to the Washington consensus on the right—and on the left, among environmentalists opposed to chemical fertilizers, road building, and irrigation projects." Thus, real per capita levels of official development assistance for the agricultural sector in the poorest countries fell by nearly 50 percent between 1982 and 1995.

Finally, Borlaug says, "Africa needs roads. Roads bring know-how and fertilizer to farmers and ideas and business for commerce." Africa, Borlaug argues, also needs concerted international help. Meanwhile, Ug99 has reached Yemen: from there, Borlaug warns, "it can reach Iraq, Iran, India, and Pakistan"—even the breadbaskets of Europe and America. A scramble is on to find resistant varieties, ensure that their yields will encourage farmers to adopt them, and produce sufficient tonnages of seed.

Last year, ABC, CBS, and NBC cameras were absent when Borlaug was presented with the Congressional Gold Medal. And alas, Borlaug's friend and biographer Leon Hesser has now produced a prosaic work that, while good on his hero's early years, fades as Borlaug appears on the international stage. Borlaug deserves better, but when journalist Gregg Easterbrook sought a publisher for a popular biography, "they said he was boring," the self-described "environmental optimist" says. "If he'd killed someone instead of saving hundreds of millions of lives, then they'd have been interested." TR

JOHN POLLOCK HAS WRITTEN AND CONSULTED ON DEVELOPMENT ISSUES FOR INTERNATIONAL ORGANIZATIONS, GOVERNMENTS, AND NONPROFIT ORGANIZATIONS, WITH A PARTICULAR FOCUS ON SUB-SAHARAN AFRICA. HE NOW WORKS FOR TURQUOISE FROG, A THINK TANK.

ONLINE MUSIC DISTRIBUTION

The Tipping Jar

RADIOHEAD IS MESSING WITH THE BUSINESS OF MUSIC.

By LARRY HARDESTY

In October 2007, the English rock band Radiohead enhanced its already enviable avant-garde credibility by releasing its seventh album, *In Rainbows*, online. Fans willing to offer up their names and e-mail addresses—or at least, fake names and fake e-mail address—could pay what they chose for the album, even downloading it for free. The band, and the "tip jar" business model it had adopted, were the talk of the music press and the blogosphere for weeks.

Just days after the release, the site Gigwise.com, citing an unnamed source "close to the band," claimed that 1.2 million copies of the album had already been downloaded. At about the same time, a survey by a British company called Record of the Day pegged the average price paid at about $8. But *Billboard*, the U.S. music industry's leading trade magazine, estimated the number of downloads at closer to 400,000, although it accepted the $8 average. And ComScore, a consumer research company based in Reston, VA, that collects data on the online behavior of a representative two million people worldwide, calculated that in the first 29 days of October, about 1.2 million people visited the Radiohead site. Although a "significant percentage" of them downloaded the album, ComScore said, the average payment was $2.26.

RADIOHEAD'S INTERNET RELEASE OF *IN RAINBOWS*
www.inrainbows.com

As of this writing, the band has declined to release any figures. Radiohead's manager dismissed the Gigwise report as "exaggerated." But band representatives also called ComScore's data "wholly inaccurate," and Ken Kovash of Mozilla, the organization that designed the Firefox Web browser, revealed that ComScore had underestimated the number of people who visited the Mozilla site in September by about 60 percent.

Billboard surmised that a conventional CD release of *In Rainbows* would have brought Radiohead between two and three million dollars. If anything like the higher sales estimates obtain, then relying on the public's largesse rather than the efficiency of record-label marketing campaigns increased the band's take. But even if ComScore's less impressive figures are right, and a "significant percentage" means no more than half, then Radiohead grossed $1.36 million in the last three weeks of October. That's still a big enough number to turn some heads.

MONEY: IT'S A GAS

The digitally compressed music file presents a conundrum that may be unprecedented in the history of commerce: soon the music industry's chief good will be one that its customers can easily acquire at no cost.

The industry's response to the threat of piracy has been threefold: to use digital rights management (DRM) software to limit illicit copying and distribution; to discourage file sharing through lawsuits; and to attempt to exploit the new technology in ways that preserve high profit margins.

By most accounts, the first two strategies are doomed and will eventually be abandoned. But the third has been much more successful. Last summer, iTunes sold its three billionth audio file, which means that it has generated around $2 billion in revenue for the record companies partnered with it. And while iTunes, which charges 99 cents per download, is by far the largest online retailer of compressed music files, it's still only one of many.

As the market for music comes to be dominated by generations weaned on file-sharing software, however, piracy is likely

to take a bigger bite out of online sales. So one of the questions the music industry will need to answer is how much it can afford to charge customers who consider payment entirely optional.

Data that address that question are hard to come by, but the online music store eMusic may, through a quirk of its business model, provide some guidance. The second-largest online retailer of compressed audio files, eMusic still lags far behind the leader: according to its CEO, David Pakman, it has only a hundredth as many customers as iTunes. Those customers pay monthly subscription fees that entitle them to fixed numbers of downloads: $10 buys 30 downloads, $15 buys 50, and $20 buys 75. Subscribers who regularly download their full monthly quota thus pay from 27 to 33 cents per MP3.

But few eMusic subscribers meet that description. Since the quotas don't roll over from one month to the next, a given subscriber's average payment per download can fluctuate widely: 30 downloads last month may have meant an average of 33 cents per MP3, but 10 this month means an average of a dollar. "Across all of our customers and all of our usage, the effective price that consumers are paying is less than 99 cents, so we don't believe that 99 cents is the right price point," says Pakman. "For non-hit music, it's probably somewhere between 60 and 75 cents a song. And that's based on data. That's not my gut. That's based on what we see people willing to pay in the market."

Pakman doesn't believe that eMusic's low prices are seducing anyone away from piracy, though. "Our customers are really not the piracy-prone customers," he says. "I think that generally, piracy is the domain of youth, and we just don't focus on the youth customer. So we don't see piracy as eating into our ability to sell music."

But what happens when today's piratical youths, unintimidated by file-sharing technology and accustomed to free music, become adults?

In 1998, Bruce Schneier, a celebrated cryptographer and chief technical officer of the network security firm BT Counterpane, proposed an answer, a mechanism he called the street performer protocol. A band would announce the completion of a new album, and the band's fans would begin paying arbitrary amounts of money into an escrow account. Once the total in the account crossed some threshold, the band would collect the money and release the new work into the public domain. Schneier showed that data encryption can ensure that the artist doesn't swipe the money without delivering the goods, and that if the payment threshold is never crossed, the contributors can all get their money back (plus interest).

But Schneier himself now believes that such measures will prove unnecessary. "In real life, you're more likely just to use trust," he says. "Radiohead just said, 'We'll do it.' They're just relying on the good will of their fans, and their fans' trust in them, and so on. And that just seems more plausible in our world."

Radiohead's reliance on the good will of its fans probably netted it more than a million dollars in the month of October, and possibly much more. But Radiohead is also the beneficiary of years of major-label publicity. In a world of unrestricted, open-format downloads, where record companies have no way to recoup the costs of huge marketing campaigns, bands will have a harder time achieving Radiohead's level of celebrity in the first place.

Nonetheless, smaller experiments with new methods of distribution and promotion also indicate that people are willing to pay more than they have to for music they care about. The Canadian folksinger Jane Siberry, who last year changed her name to Issa, began using the tip-jar model to sell her recordings a good two years before Radiohead did, although her website recommends that customers pay the industry standard 99 cents a song. According to statistics posted on the site, about 20 percent of downloaders pay nothing. But the average payment per song is still $1.20. Magnatune, a website that sells 569 albums by 258 artists, lets its customers choose how much to pay but sets a lower bound of $5 an album. Its 50 top albums, however, sell for an average of $8 to $10. In a slightly different vein, Team Love Records posts all of its artists' recordings to its website as free, high-quality MP3s. But its most popular acts still sell thousands of CDs, which is pretty good for a small independent label.

It may be that in the brave new world of Internet music distribution, rock bands will no longer generate so much revenue that they can afford to throw TVs out of hotel windows or insist that all the brown M&Ms be removed from the candy bowls in the greenroom. But Radiohead's online release of *In Rainbows* contributes to the mounting evidence that musicians who build an audience will still be able to make a living doing what they love. TR

LARRY HARDESTY IS A *TECHNOLOGY REVIEW* SENIOR EDITOR.

ROBIN SELLICK/HEADPRESS/RETNA

A LINUX COMPUTER

Most electronic devices, because of their limited memory and processing power, must be programmed using languages and techniques that are difficult to master. But the Linux computer at the heart of Bug Labs' modular device provides tools that let users program applications more easily. The technically inclined can program in Java, a widely known language, and make their programs available to other users. The device has enough memory to store multiple programs, so it can perform many different functions when the proper modules are connected.

Bug Labs

A NEW COMPANY MAKES A MODULAR ELECTRONIC DEVICE.

By ERICA NAONE

WITH ITS OPEN-SOURCE, modular approach to personal electronics, New York's Bug Labs could be on to something big. Its beautifully designed flagship device, the Bug, is a central base about the size of an iPhone that can be programmed to serve as a custom-designed gadget with the help of snap-in modules. To maximize its flexibility, a user needs to be able to program in Java, so initially, the Bug may be of interest only to hobbyists. But the company is building up a library of programs and designs that will be easy for the average person to use. The Bug, and the first modules made for it, began shipping at the end of 2007.

B COMMON CONNECTIONS

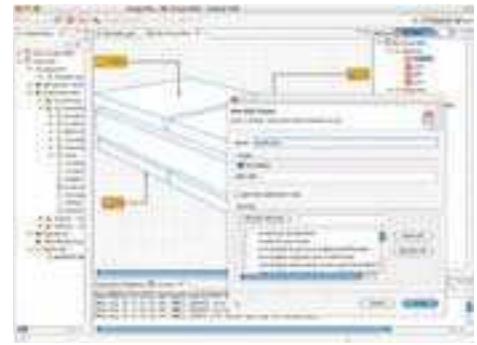
Rather than use a customized connector for each module that snaps into its base, the Bug relies on standard 40-pin connectors. "It's a very low-tech, brute-force method, but we didn't want to get into the cable business," says Bug Labs CEO Peter Semmelhack. In addition, the sides of the base feature USB, Ethernet, power, and memory ports. The Bug contains embedded software designed to recognize modules. To avoid crashes, the software prevents programs from running unless all the necessary modules are plugged in. For example, a program that tells the Bug how to take geotagged photographs will run only if the system detects the camera and GPS modules.

C MODULAR DESIGN

Modules currently available for the Bug include a camera, a motion detector, a GPS receiver, and a touch-sensitive color LCD screen. On the way are a mini QWERTY keyboard, an audio speaker with mini input/output jacks, and an LCD screen twice the size of a regular module. Technically inclined users can also design and build their own components for the Bug, connecting them through the Von Hippel module—named for MIT professor Eric Von Hippel, who advocates making it possible for people to participate in the design of the products they use. The module is a plastic case, empty except for the tools necessary for a user to connect it to the base.

D SIMPLE DOWNLOAD

A drag-and-drop interface allows users to easily download or upload Bug programs. An online development environment, which works much like iTunes, can be accessed through a user's computer. When the Bug is connected to a computer by a USB cable, the development environment detects it and its connected modules and displays popular programs using the given configuration. A user can download the programs by dragging their icons onto the Bug icon. If the user changes the Bug's physical configuration, the change is mirrored on-screen in the development environment.



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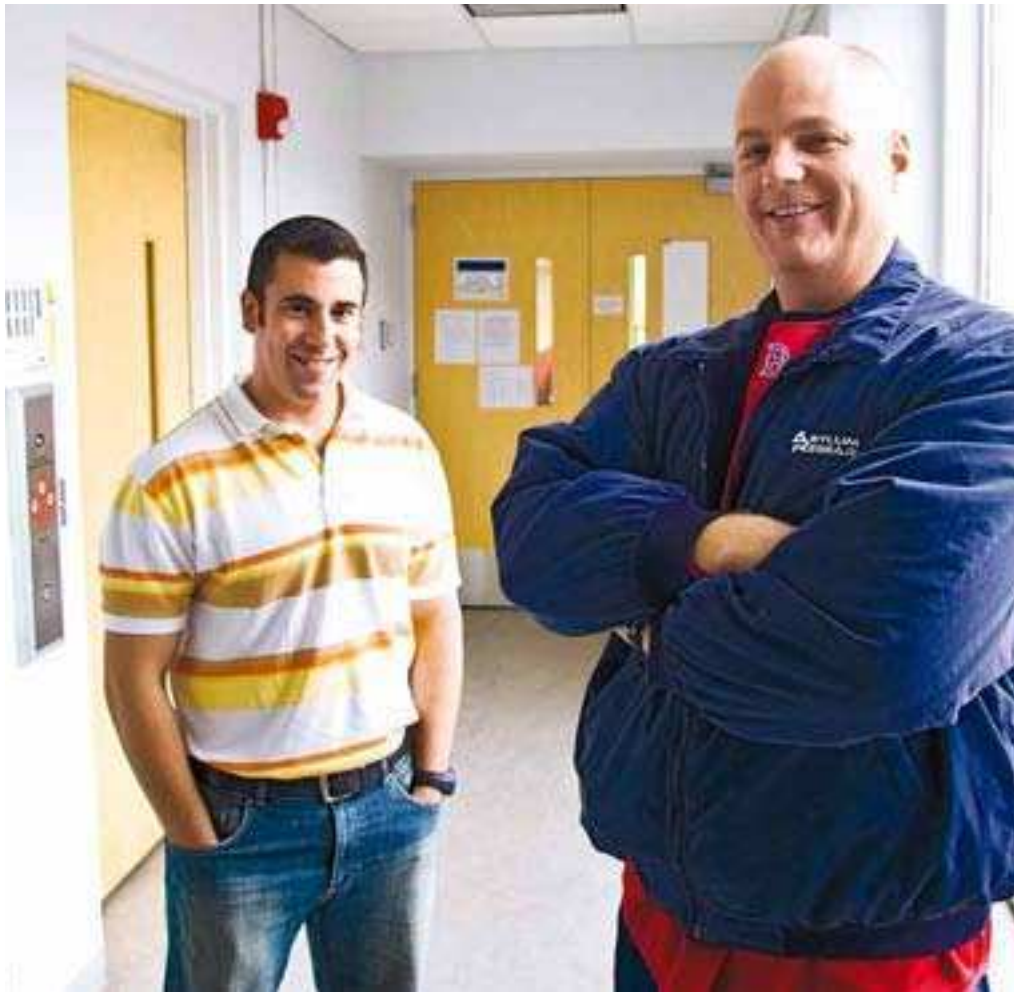
E COMMUNITY ELECTRONICS

In the spirit of the open-source movement, Bug Labs makes available all the schematics of its hardware. Users can collaborate through the development environment, sharing programs for the device and ideas for different configurations.

WWW The CEO of Bug Labs explains his startup: **technologyreview.com/hack**

DAVID ARKY



Tiny Living Machines

DEVICES MADE OF HEART TISSUE COULD SCREEN DRUGS AND POWER IMPLANTABLE ROBOTS.

By KEVIN BULLIS

In a fourth-floor lab at Harvard University, Adam Feinberg is peering through a low-magnification microscope and using a scalpel to cut out triangles and rectangles from a thin polymer. What's impossible to see with the naked eye is a one-cell-thick layer of heart tissue coating each shape. When Feinberg connects the petri dish holding the triangles and rectangles to a pacemaker, the tissue begins to rhythmically contract, and the shapes come alive—twisting, pinching, and even swimming through a solution.

The pieces of "muscular thin films" are just a few millimeters long and only 30 micrometers thick; at first glance they resemble small worms you might find wiggling in a mud puddle. Kevin Kit Parker, the professor of biomedical engineering who heads the Harvard lab, jokes that he's planning to retire to the South, where he was raised, and sell them as customizable lures in a bait shop.

But the experiment has entirely serious implications. Eventually, the patches of twitching tissue could be used as actuators for tiny robotic devices implanted in the body. The muscle cells would be fueled by sugar in the bloodstream and maintained by the same repair mechanisms that keep the heart pumping. Parker says the muscle-coated film could also be used to regenerate tissue damaged in heart attacks. But such applications are quite a way off, he says. In the nearer term, the devices could be used to help researchers monitor how experimental medicines change the behavior of heart muscle.

PRINTING TISSUE

This is not the first time researchers have grown beating heart muscle in a dish. But Parker and Feinberg, a postdoctoral researcher in Parker's lab, have found ways to make the tissues far more powerful, contracting with the same strength as natural heart tissue.

The manufacture of the devices begins with a biological printing technique, developed by Harvard chemists, that can deposit proteins in microscopic patterns on various surfaces. Parker and Feinberg use the method to precisely organize the heart cells into working tissue.

The process looks unremarkable. Working in a sterile laboratory hood, Feinberg arranges a few chunks of clear silicone rubber in a petri dish. The chunks are stamps patterned with an array of microscopic lines. The pattern was created by molding the stamps to a wafer of silicon etched using the same techniques that produce micro-

PHOTOGRAPHS BY PORTER GIFFORD

HEART STAMPS Adam Feinberg (far left), a postdoc at Harvard, and Kevin Kit Parker, a professor of biomedical engineering, make tiny machines out of rat heart tissue. Feinberg uses a pipette (top) to apply a protein called fibronectin to a clear polymer stamp patterned with microscopic lines. He presses the stamp onto a silicone-coated coverslip (left), transferring lines of the protein to the silicone. Then he immerses the coverslip in a solution of heart cells (red liquid above). The protein lines direct the growth of heart tissue.

chips. Onto each stamp Feinberg squirts a clear "ink" that contains a common protein called fibronectin. As the stamp dries, a thin layer of the protein forms. Holding a stamp with a pair of forceps, Feinberg presses it onto a round, silicone-coated glass coverslip, transferring proteins from the raised portion of the microscopic pattern to the silicone film.

With the protein patterns stamped out and ready, Feinberg immerses the coverslip in a solution of young, still developing heart cells harvested from rats. The cells begin to adhere to the fibronectin, forming orderly lines. Feinberg then puts the cells and the protein-patterned coverslip, still immersed in the solution, into a body-temperature incubator. Over the next few days, the lines of fibronectin guide the cells' organization and further development. Long, fiberlike contractile units begin to form, guided by the cells so that they line up parallel to the lines of protein. If they weren't aligned this way, the cells would fight against each other as they contract rather than pulling in the same direction. The aligned cells, however, all contract along the same axis, much the way they do in natural heart tissue.

When Feinberg removes the newly grown tissue from the incubator, it and the film of silicone it's printed on are immobilized by the rigid glass coverslip. But as they cool, a temperature-sensitive glue that holds the silicone to the glass begins to dissolve. Feinberg has just a few minutes to cut out shapes before the silicone and tissue float free. Once they do, the heart tissue can contract, making the film to which it's anchored start bending and twisting.

So far Feinberg has made rudimentary pumps, twisting actuators, pincers, a device that slowly swims, and another that walks

IT'S ALIVE! Adam Feinberg has made a simple heart-muscle-powered actuator: a strip of polymer (bottom left) that flexes when the muscle contracts. Through a low-powered microscope, the orientation of the muscle tissue is visible (above) near the point where he grips the elastic film with a pair of forceps. Feinberg controls the rate of the contractions by changing the frequency of electronic pulses (top left).

along the bottom of a petri dish. A long rectangular strip, cut from the film so that the lines of cells run along its length, curls up with each contraction. Another rectangle, cut at a slight angle to the cells, coils up into a corkscrew. The narrow "tail" of a triangular piece propels the shape through the solution. The behavior of these devices can be controlled like that of a natural heart: with a pacemaker. Feinberg hooks electrical leads to the small dish holding the devices. Low-voltage bursts of electricity travel through the solution, signaling the muscle to contract.

MUSCLES ON DRUGS

A practical way to measure the effect of drugs on heart tissue is to determine how strongly treated tissue can contract. Thus, the device likely to be most useful in the short term is also one of the simplest: a long rectangular strip of tissue that bends slightly with each pulse of electricity. These devices could be used both to screen drugs meant to act on the heart and to identify drugs that may adversely affect the heart.

Because the mechanical properties of silicone are well known, it's possible to determine exactly how much force the heart tissue is exerting by measuring how much the strip bends. If a change is observed in the amount of force the cells can exert, it's a sign that a drug is having an effect. Parker envisions a testing system of small wells, each containing a strip of silicone and heart muscle. Such a system could be used to measure the effects of different compounds, or different concentrations of the same compound, on the heart tissue's ability to function. The system could even be automated; Feinberg has already developed software that analyzes video of the strips and calculates changes in the amount of force the tissue exerts.

So far, the researchers have used only rat cells. Eventually, they hope to make screening tools with human cells, perhaps by first growing stem cells and then coaxing them to develop into heart cells. They also hope to make similar systems with muscle cells that line blood vessels—to test hypertension drugs, for example. For other applications, the devices will have to be made either smaller (for implantable robots) or larger (for patches that help heal damaged hearts).

Ultimately, the key to the technology may be its simplicity, which could make it easy to adapt to a range of applications. As Parker says, "We have dummy-proofed this technology so that it is easy to learn, easy to do, and eventually, easy to deploy in the clinic." TR

WWW Watch a piece of heart tissue swim: **technologyreview.com/demo**

KEVIN BULLIS IS THE NANOTECHNOLOGY AND MATERIALS SCIENCE EDITOR OF *TECHNOLOGY REVIEW*.

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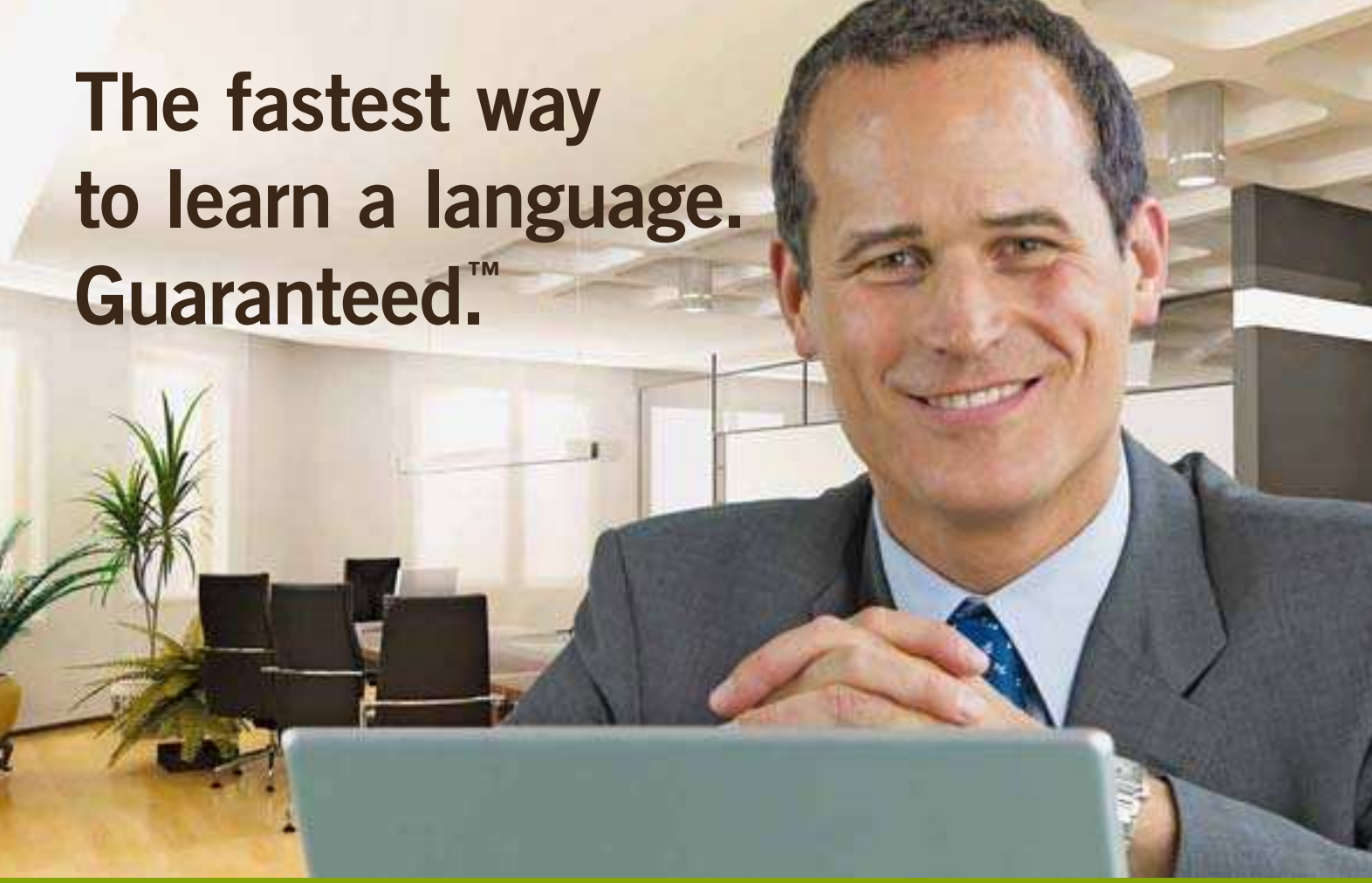

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FROM THE LABS

INFORMATION TECHNOLOGY

Fixing Bugs in Hardware

SOFTWARE DIAGNOSES PROBLEMS IN CHIP PROTOTYPES AND OFFERS FAST, CHEAP SOLUTIONS

SOURCE: "AUTOMATIC POST-SILICON DEBUGGING AND REPAIR"
Valeria Bertacco et al.
International Conference on Computer-Aided Design, November 6, 2007, San Jose, CA

Results: Researchers at the University of Michigan have developed software that finds flaws in computer chips and proposes economical fixes. The software is able to repair about 70 percent of bugs.

Why it matters: Before a chip is mass-produced, a prototype is shipped from the fabrication facility to the chip designers for testing. Currently, engineers can spend up to a year manually inspecting a prototype for mistakes, such as design errors, misplaced transistors, or wires that are too close together. Each time flaws are identified and corrected, a new prototype has to be made and tested. Each iteration can cost millions of dollars, and repeated prototyping delays commercialization. Manual bug-hunting is also prone to error and may result in products with faults that can be exploited by computer viruses.

Methods: Engineers test chip prototypes by hooking them up to probes that send electrical stimuli through them and record the output. The Michigan researchers wrote software that quickly runs through thousands of input signals and analyzes the output, zeroing in on problem areas. Likewise, it identifies ways to fix bugs by running through a series of simulations to find a design variation that offers the fastest and most cost-effective solution, one that may not be obvious to an engineer looking at a wiring diagram.

Next steps: The researchers are looking into some of the debugging challenges specific to multicore processors—chips with more than one processing center.

Building a Nano Radio

A RADIO RECEIVER MADE FROM A CARBON NANOTUBE COULD BE USED TO WIRELESSLY TRANSMIT DATA FROM ULTRASMALL SENSORS

SOURCE: "NANOTUBE RADIO"
Alex Zettl et al.
Nano Letters 7: 3508–3511

Results: Researchers at Lawrence Berkeley National Laboratory in California have modified a carbon nanotube so that it performs the functions of a radio, even tuning in the entire FM radio band.

Why it matters: Radios are used in everything from cell phones to nodes in sensor networks, and like other electronics, they are shrinking in size. A nanoscale radio could someday find its way into portable electronics such as cell phones. The researchers also suspect that with its small size, the radio could be inserted into a biological cell to transmit information collected by tiny sensors that detect molecular processes.

Methods: The researchers grew the carbon nanotube on a tungsten surface that acts as a negative electrode; a positive copper electrode is separated from the nanotube by a vac-

This carbon nanotube, imaged by a transmission electron microscope, can act as a radio.

COURTESY OF THE ZETTL RESEARCH GROUP, LAWRENCE BERKELEY NATIONAL LABORATORY, AND THE UNIVERSITY OF CALIFORNIA, BERKELEY

uum gap. A voltage applied to the electrodes causes a current to flow through the nanotube, turning the radio on. Changing the voltage also changes the vibrational rate of the nanotube, tuning it to a different frequency.

Next steps: The researchers are looking to integrate the radio into biological systems.

NANOTECHNOLOGY

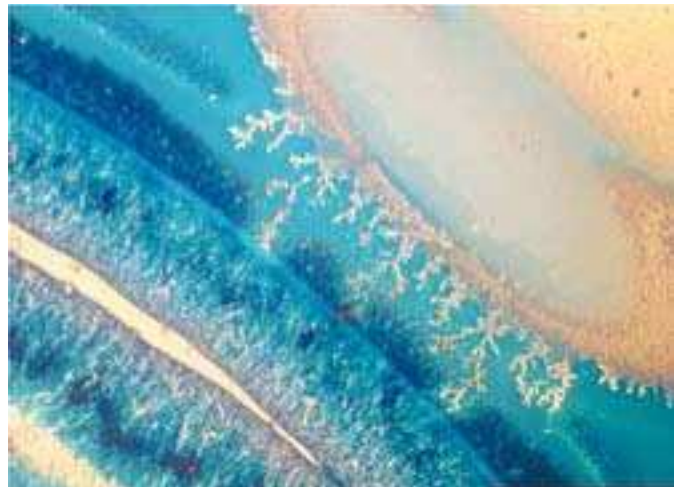
Terabyte Nonvolatile Memory

A FLASH ALTERNATIVE COULD STORE A TERABYTE OF DATA

SOURCE: "BIPOLAR AND UNIPOLAR RESISTIVE SWITCHING IN Cu-DOPED SiO_2"
Christina Schindler et al.
IEEE Transactions on Electron Devices 54: 2762–2768

Results: Using silicon and copper, researchers have made a new type of memory that stores information by harnessing negative and positive charges to assemble and disassemble nanoscale metallic wires. Each memory cell consists of two electrodes separated by an electrolyte doped with copper ions. When a cell is in the off state, little current passes from one electrode to the other. When a "writing" voltage is applied, the ions line up and form a filament that bridges the electrodes, markedly increasing current. Reversing the voltage causes the filament to dissolve.

Why it matters: The technology could lead to memory devices that hold more information, since each binary bit could be stored in wires just a couple of atoms thick. The new memory devices could be used to replace flash memory, eventually making it possible to store a terabyte of data on a cell phone or music player. Similar ionic memory devices have been made before in the lab, but they relied on more exotic materials. Chip makers might be more likely to consider adopting this new type of memory if they could use materials common in semiconductor manufacturing.



Copper wires (small branching structures, above) grown by applying a voltage to copper-doped tungsten could be the key to a new type of ultradense memory.

Methods: The researchers used standard techniques to deposit and pattern a tungsten electrode, a layer of silicon dioxide, and a copper electrode. By heating the layers to more than 600 °C, the researchers then caused copper ions from the electrodes to diffuse into the silicon dioxide, forming the copper-doped electrolyte.

Next steps: The researchers need to optimize the performance of the memory cells and determine how many read-write cycles they can survive. To reach terabyte densities, it will be necessary to fabricate multilayer memory devices and store multiple bits of information on each wire; both feats should be possible with the new technology.

Novel Drug Synthesis

A NEW CATALYST COULD REDUCE WASTE AND LEAD TO NEW DRUGS BASED ON NATURAL PRODUCTS

SOURCE: "A PREDICTABLY SELECTIVE ALIPHATIC C-H OXIDATION REACTION FOR COMPLEX MOLECULE SYNTHESIS"
Mark S. Chen and M. Christina White
Science 318: 783–787

Results: A new iron-based catalyst developed by researchers at the University of Illinois at Urbana-Champaign enables researchers to predictably alter the cores of complex molecules by oxidizing specific carbon-hydrogen bonds.

Why it matters: Complex molecules produced by plants and other organisms are often good candidates for new drugs. But they frequently need to be chemically modified before they're effective enough for therapeutic use. In the past, making the necessary modifications could require synthesizing the entire molecule from scratch, often a difficult process requiring multiple steps. The new catalyst makes these modifications easier.

Methods: The researchers synthesized a catalyst that was both relatively large and attracted to electrons. Then they derived a list of rules predicting precisely which bonds in complex molecules the catalyst would oxidize. They showed that in general it oxidized the carbon-hydrogen bond at the most electron-rich area of a complex molecule. If, however, the most electron-rich area was difficult to reach, the catalyst oxidized the most accessible C-H bond. Finally, if the molecule included a carboxylic acid group, the catalyst oxidized a bond a certain distance from the acid. The researchers confirmed that the rules allow chemists to predict exactly which bond will be modified.

Next steps: Researchers at other academic institutions and drug companies are beginning to use the catalyst in their work. The University of Illinois researchers are

CHAKKU GOPALAN

considering new catalysts that work on similar principles.

BIOTECHNOLOGY

Deciphering Human Differences

CHUNKS OF SHUFFLED DNA IN THE HUMAN GENOME COULD UNDERLIE MANY DISEASES

SOURCE: "PAIRED-END MAPPING REVEALS EXTENSIVE STRUCTURAL VARIATION IN THE HUMAN GENOME"
Michael Egholm, Michael Snyder, et al.
Science 318: 420–426

Results: Scientists have uncovered extensive regions in the human genome where chunks of DNA have been deleted, copied, or completely rearranged. More than a thousand structural variations were identified between two individual genomes—many more than other studies have found.

Why it matters: Most studies of genomic variation have focused on individual bases, or DNA "letters." In the last few years, however, several studies have shown that structural variations in DNA may be at least as important as single-letter variations. Mapping and characterizing these structural variants could be key to understanding human diversity and the origins of many diseases.

Methods: Snyder and his colleagues analyzed the genomes of two individuals, one of African descent and one of European descent. They chopped the genomes into millions of fragments, each 3,000 bases long, and tagged the fragments' ends. They then sequenced the ends of each fragment and compared them with a reference genome, derived from the Human Genome Project. If the overall sequence of the fragments was either shorter or longer than the corresponding piece of the reference genome, the researchers concluded that a piece of DNA had probably been copied or deleted.

Next steps: The company whose sequencing technology was used in the study, 454 Life Sciences of Branford, CT, aims to repeat the experiment on 100 individuals. Scientists eventually aim to generate an inventory of the structural variations associated with human disease.

Cellulose Enzymes from the Termite Gut

A METAGENOMIC STUDY OF THE MICROBES THAT LIVE IN WOOD-EATING TERMITES COULD SUGGEST NEW WAYS TO MAKE CELLULOSIC ETHANOL

SOURCE: "METAGENOMIC AND FUNCTIONAL ANALYSIS OF HINDGUT MICROBIOTA OF A WOOD-FEEDING HIGHER TERMITE"
Jared R. Leadbetter et al.
Nature 450: 560–565

Results: In a massive genomic study of the microbes living within the termite gut, scientists may have identified close to a thousand enzymes that break down wood.

A massive genetic analysis of the microbes in the gut of *Nasutitermes* termites, shown here, could yield more efficient enzymes for generating cellulosic ethanol.

RUDOLF H. SCHEFFRAHN, PROFESSOR OF ENTOMOLOGY, UNIVERSITY OF FLORIDA

Why it matters: Biofuels made from cellulosic biomass, including cornstalks, perennial grasses, and wood chips, could provide a cheaper and more environmentally beneficial alternative to corn-derived ethanol. However, breaking down cellulose into simple sugars that can be fermented into ethanol is a complex, inefficient, and expensive process. The newly identified cellulose-digesting proteins could shed light on termites' wood-eating capacity and suggest cheaper, more efficient enzymes for generating cellulosic ethanol.

Methods: Scientists collected *Nasutitermes* termites from Costa Rica and isolated DNA from the microbes living in part of the insects' gut. They then sequenced and analyzed the genomic material from the many different types of bacteria, searching for particular sequences known from other studies to be linked to the ability to break down cellulose.

Next steps: Researchers are now testing some of the newly identified microbial enzymes for their wood-digesting ability, as well as searching for combinations of different enzymes that work together synergistically. TR

Alumni-to-Alumni Directory

Classifieds

Oil Rigging an Election

POLITICS CONTINUE TO COMPLICATE ENERGY POLICY.

By MICHAEL PATRICK GIBSON

When the New York Mercantile Exchange closed the day before Thanksgiving, a barrel of crude oil cost over $97, roughly matching the inflation-adjusted record high set in 1980.

As the baleful effects of soaring oil prices ripple through the economy, the quest for an oil substitute becomes political, especially when presidential candidates stumping in Iowa before the caucuses have to pledge to preserve or expand subsidies to the corn-based U.S. ethanol industry.

It is a time-honored campaign strategy: if energy prices are scaring the electorate, promise to develop alternative fuels. In the summer of 1979, President Jimmy Carter promised that with his energy plan, the United States would "never use more foreign oil than we did in 1977." A year later, he signed the Biomass Energy and Alcohol Fuels Act into law, allocating $600 million to the production of fuels from agricultural crops, agricultural wastes and residues, wood and wood wastes and residues, animal wastes, municipal wastes, and aquatic plants. Much of the money was devoted to research on cellulosic ethanol, currently the most promising biofuel in development *(see "The Price of Biofuels," p. 42)*.

In any case, Carter lost the election to Ronald Reagan in a landslide, the price of oil declined to levels tolerable to the electorate, and just as he pledged, President Reagan slashed the budget. By August 1981, funding for Carter's Biomass Act had been reduced to $460 million. The money soon dried up.

In the August/September 1979 issue of *Technology Review*, Philip Shabecoff, then a writer for the *New York Times*, argued in "The Current Politics of 'Synfuels'" that politics should not diminish the importance of developing synthetic fuels, which include clean-burning coal and crude oil made from oil shale. Shabecoff wrote:

President Carter's call for a "fast track" development of synthetic fuels was, in large measure, a response to a political problem—his own waning prospects for re-election in 1980. Politics, therefore, is likely to determine just how far the "synfuels" program goes.

The ninety-sixth Congress has been notably timid and unproductive, given to darting off in a new direction with every shift of political current like a school of nervous fish. When the gasoline lines started forming early in the summer, Congress feverishly embraced synthetic fuels as an answer to take home to angry constituents. But when the lines disappeared in most of the country, the Congressional will to deal boldly with the energy crisis began to dissolve into the irresolute bickering that has characterized the legislative branch over the past couple of years.

If the synthetic fuels program is to move forward at the pace outlined by the President, it must be launched with the momentum of full national consensus. The technology to carry such a program to fruition exists, the policy makers believe. And there is little argument with the national security rationale for relieving dependence on foreign sources of energy. ...

Economic issues are likely to form a particularly difficult political barrier to Mr. Carter's program. For one thing, the cost of developing the synthetics program is going to be high. According to an analysis by the Rand Corporation, the crash program envisioned by the President could easily cost twice the $88 billion price tag he put on it. The capital absorbed by the program will drain funds that would otherwise be invested in different sectors of the economy. ...

It will be some time before the intrinsic merits of competing energy strategies can be fully weighed. But a political decision will be made soon. The future of synthetic fuel development will probably be determined by how the issue is treated by the candidates for office in 1980—and how the voters respond. TR

JON MCINTOSH

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